THE ADVANCEMENT OF Science

LATIN AMERICA

The Development of its Civilization

H. M. BAILEY & A. P. NASATIR

A one-volume history of Latin America combining political, economic, social and cultural developments, with a broad coverage of the twentieth century.

Med. 8vo. 818 pp. Illustrated 60s.

INTRODUCTION TO THEORETICAL METEOROLOGY

S. L. HICKS

Covers, simply and clearly, all the important elements of dynamic meteorology.

Med. 8vo. 362 pp. Illustrated 60s.

LIVING EARTH

PETER FARB

The Director of the *Commonwealth Bureau of Soils* thought this the most interesting and perhaps the best book on the biology of the soil he had read.

178 pages Illustrated 21s.

PRE-HISTORIC MAN IN EUROPE

F. C. HIBBEN

Based on extensive notes compiled by the late Vladimir Fewkes, this book gives an account of European prehistory from the Eolithic age.

Med. 8vo. 334 pp. Illustrated 50s.

EXPLANATION OF HUMAN BEHAVIOUR

F. V. SMITH

An examination of the contributions of seven major psychologists to the theory of human behaviour. A chapter devoted to Freud's system has been added to this edition.

Second edition Demy 8vo. 300 pp. Illustrated 30s.

Recent Dover Paperbounds:

CHANDRASEKAR: *Principles of Stellar Dynamics. 16s.*

LAMB. *Dynamical Theory of Sound. 12s.*

MCLACHLAN: *Loud Speakers. 18s.*

MAXWELL: *Treatise on Electricity & Magnetism.* 2 vols. *each 16s.*

MENZEL: *Fundamental Formulas of Physics.* 2 vols. *each 16s.*

CONSTABLE & CO. LTD.

10–12 ORANGE STREET, LONDON, W.C.2

The Institute of Physics and The Physical Society

The Institute of Physics and The Physical Society were amalgamated in 1960, the objects of the new body being the advancement and dissemination of a knowledge of physics and the elevation of the profession of physics.

There are four grades of full membership:

(*a*) FELLOW OF THE INSTITUTE OF PHYSICS

(*b*) ASSOCIATE OF THE INSTITUTE OF PHYSICS

(*c*) GRADUATE OF THE INSTITUTE OF PHYSICS

(The above are all professional grades)

(*d*) FELLOW OF THE PHYSICAL SOCIETY

Full details of membership, including the non-member grades of Student and Subscriber, may be obtained from:

THE INSTITUTE OF PHYSICS AND THE PHYSICAL SOCIETY

47 Belgrave Square, London, S.W.1

All enquiries regarding

ADVERTISEMENTS

in the publications of the

BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

should be addressed to the authorised advertisement contractors:

J. M. P. PUBLISHING SERVICES

STAFFORD HOUSE, NORFOLK STREET, LONDON, W.C.2.

Telephone : TEMple Bar 9525, 9410

THE ADVANCEMENT OF Science

VOL. XVII No. 69 JANUARY 1961

Editorial Committee Emeritus Prof. L. Dudley Stamp, C.B.E. (*Chairman*)
Prof. L. F. Bates, F.R.S., Mr. G. C. E. Smith, Dr. W. E. Swinton

Editor J. M. Robertson

ARTICLES

The Structure of the Universe, *by Prof. H. Bondi, F.R.S.* 401

Non-Auditory Effects of Noise, *by D. E. Broadbent* 406

Oceanography in the I.G.Y., *by Prof. G. E. R. Deacon, C.B.E., F.R.S.* 410

The Geographical Variations of Disease Mortality in England and Wales in the Mid-Twentieth Century, *by Dr. G. Melvyn Howe* 415

Vernacular Plant Names and their Background in Norway, *by Prof. Dr. Ove Arbo Høeg* 426

The Place of Psychology in the Sciences and the Technologies, *by Prof. C. A. Mace* 436

Physics in the Steel and Metal Industries, *by M. R. Hopkins* 442

The Dangerous Concept of the Natural Forest, *by T. R. Peace* 448

The Role of Universities in Teaching Technology, *by Prof. M. W. Thring, F.R.S.* 456

What the Octopus makes of it; Our World from another Point of View, *by M. J. Wells* 461

What Fertilisers could do to Increase World Food Production, *by Dr. H. L. Richardson* 472

MEMORANDA

Notes and Comments 397

British Association News 433

Looking at Science 481

Echoes from the Past 484

Books 486

Published six times a year by The British Association for the Advancement of Science
18 Adam Street, Adelphi, London, W.C.2. *Telephone: Trafalgar 5733/4*

Subscription Rate: Per annum 40s. *post free* ($6). *Single copies* 7s. 6d. *plus postage* 7d. ($1.25 *post free*)

Advertisements: J.M.P. Publishing Services, Stafford House, Norfolk Street, W.C.2. (*Tem. 9525*)

Food, Land and Manpower in Western Europe

P. LAMARTINE YATES

A study of the contribution that the farm economy of Western Europe could make to general economic expansion is the central theme of this new study of the region's food supply and agricultural problems. The first of a series of four monographs being prepared on European problems. *35s.*

Biography of the Earth

Second Edition

GEORGE GAMOW

Originally published eighteen years ago, this well-known book has been completely revised in the light of important post-war developments in our knowledge of the Solar System, thereby providing an up-to-date view of the history of the earth and its place in the Universe.

Illustrated with photographs and diagrams. 35s.

Structural Concrete

KURT BILLIG

This work follows Professor Billig's previous books *Prestressed Concrete* and *Precast Concrete*, published a few years ago. These previous volumes dealt with two of the main branches of structural concrete, while the aim of this present work is to provide a *Minor Encyclopædia on Structural Concrete* within a single volume. *164 figures, 75 photographs, 113 tables. 84s.*

World Without End

ROGER PILKINGTON

A brilliant account of how a man brought up in a strictly scientific training can fearlessly look at his Christian beliefs and draw encouragement rather than doubt from the startling findings of modern research. ' Here is a man who writes fearlessly and evocatively about both Science and Religion, re-creating for us a most wholesome sense that all Truth is one.'—*Canon J. B. Phillips.*

12s. 6d.

MACMILLAN & CO LTD

St Martin's Street London WC2

Notes and Comments

The significance of the rumen

The study of rumen function by our agricultural research institutes has so far been largely of a fundamental and exploratory nature but already possible practical applications can be seen. In the ruminant as much as 60 per cent of the nutrients of the feed are absorbed in the rumen and reticulum, before reaching the intestine. The rumen micro-organisms play a major role in this. From the fermentation of the carbohydrates fatty acids are formed. It has been estimated that short-chain fatty acids entering the bloodstream are sufficient to satisfy the maintenance requirements for energy of normally fed sheep and cattle. The fat in the diet of dairy cows has no direct effect on the butterfat content of milk, and there is no evidence that essential fatty acids are synthesised from it, but the butyric and acetic acids resulting from cellulose fermentation are used; a supply of adequate roughage in a form which stays in the rumen long enough for the formation of these acids may well be a method of ensuring a satisfactory level of butterfat. Appropriate micro-organisms may act on protein supplied in forms which would be unsuitable for simple-stomached animals, or on non-protein nitrogen, eventually producing essential amino acids. It is difficult to strike a balance between losses of nitrogen caused by degradation of protein nitrogen to ammonia and the gains due to microbial synthesis of amino acids essential to the host animal. So it can be seen that the quality of protein, hitherto related to the amino acids contained therein is of less importance than its solubility. The use of non-protein nitrogen, particularly with readily available carbohydrate, has already found wide practical application as urea to replace protein supplements. The importance of solubility has a bearing on processing and preparation of feeds. As the knowledge of rumen digestion is extended it will be applied to choice of more suitable and more economical feeds.

D. P. CUTHBERTSON

The Indian Ocean

The International Indian Ocean Expedition which is being planned by a special committee of the International Council of Scientific Unions will begin later this year and carry on until 1964. Peak activity is expected to occur during 1962 and 1963 when ships and scientific personnel from more than a dozen countries will be conducting basic research in physical and chemical oceanography, meteorology, marine biology, geophysics and submarine geology.

Physical characteristics.—Although the Indian Ocean's 28,000,000 square miles cover over 14 per cent of the earth's surface, relatively little is known or understood about the region, which has an area five and a half times that of Antarctica and greater than that of Asia and Africa combined. The Ocean's behaviour affects all these continents, yet only the most general features of its topography and circulation and the distribution of living organisms are known.

The Indian Ocean has several unique characteristics. Nowhere else in the world is there a similar seasonal reversal of the prevailing wind. The wind system in that part of the Ocean lying above the equator is characterised by the two monsoons, one blowing from the north-east for approximately six months and the other blowing from the south-west for the rest of the year. This phenomenon has a vast but essentially still unknown effect upon the currents and organisms in the waters.

Another notable feature is the apparent productivity of this Ocean. In June 1957, a Russian ship not far from the main trade route between Colombo and the Gulf of Aden reported millions of tons of dead fish floating in an area some 1,000 km. long and 200 km. wide extending across the middle of the Ocean. Similar reports came simultaneously from British ships in the region. It is not known how the fish were killed, but the very size of this catastrophe gives some idea of the

potential mid-ocean resources which are currently untapped.

The Indian Ocean is one of our last unexplored frontiers. Since 1873, fewer than two dozen vessels have carried out oceanographic investigations there. Modern techniques have been used only in quite limited areas. No systematic study has been attempted nor do the combined profiles of the observations reported give more than a preliminary picture of the Ocean's behaviour and characteristics.

Socio-economic characteristics.—Many of the nations lying in the tropical and sub-tropical regions which surround the Indian Ocean are among the world's most densely populated countries, with continuing rapid growth. Over a quarter of the world's people live in these countries.

Population pressures on the existing food supplies result in prevalence of diseases attributed to protein starvation. Such protein deficiencies are common in India, Ceylon, Indonesia, Malaya and in parts of the east coast of Africa. Some of the nations bordering the Indian Ocean have a seafaring tradition and conduct extensive fisheries. To feed their crowded populations, they are interested in expanding these fisheries.

Practical implications.—The proposed research will provide fundamental and valuable scientific knowledge. Some findings will have direct and immediate bearing on economic development and human welfare. Location of shoals and regions of upwelling will identify likely fishing areas. Studies of distribution, nature, and seasonal variation in nutrients and marine organisms will indicate what to fish for and when. Preliminary quantitative estimates of fish population, when supplemented by exploratory fishing, will suggest the magnitude of the fishery resource.

The data obtained will provide an essential part of the information on which decisions can ultimately be reached on the nature of fishery operations, markets and methods of marketing, extent of investment, and related development problems. A new source of protein could mean food for hungry people. If it came from the ocean, land and other capital devoted to protein food raising could be shifted to other uses. Marine organisms could also provide fertiliser and animal feed in areas now lacking adequate supplies.

Meteorological information, related to oceanographic knowledge, will be obtained on a synoptic basis. This may lead to better long-range weather forecasting. The ability to predict the onset of the monsoon and to estimate variations in the quantity of rainfall bears directly on flood control and on water regimen for agricultural use. The understanding of variations in location and intensity of ocean currents can lead to more economic routeing of ships. Such knowledge applied in the North Atlantic has resulted in savings of as much as 10 per cent in fuel consumption.

Charting and sampling the ocean floor through soundings, cores, geophysical measures, dredging and photography provide information useful for navigation and fisheries and may reveal resources of economic value.

Finally, as never before, intensive training and experience in oceanographic research will be available to residents of a maritime area. Possibly 20 vessels, with facilities for about 350 scientists, will operate on the Expedition. Data processing centres and biological classification laboratories will serve as nuclei for post-Expedition scientific development around the Indian Ocean.

In other parts of the world, the focus over several years on the International Indian Ocean Expedition will, it is hoped, serve to attract students to the field of oceanography, and thus help to relieve a world shortage of marine scientists.

No Shortage of Salt

New large deposits of salt have been discovered in the Cheshire Basin as the result of deep boring by the Geological Survey of Great Britain. The boring operations—including one borehole to a depth of slightly more than 5500 ft.—have revealed reserves of salt estimated at about 400,000 million tons.

For some years the Geological Survey's North-West England field unit has been making a six-inch to the mile geological survey of the Cheshire Basin and its extension into North Shropshire—an area of some 800 square miles, including the well-known Cheshire salt field.

To gain further geological knowledge of this area, which has extensive superficial deposits of sands, gravels and boulder clay overlying the solid rocks, exploratory boreholes were essential. In 1953–4, ten boreholes were drilled in the Stockport

area and in 1958–9, fifteen were drilled in the Cheshire–Nantwich areas. The depths of the boreholes varied from 300 to 1000 ft.; they helped considerably to prove the structure and extent of the salt field.

To knit these results together and to prove the complete succession of these salt-bearing rocks, a deeper borehole was drilled farther to the south on a site at Wilkesley Farm, five miles east of Whitchurch.

The Wilkesley Borehole has proved an upper saliferous group—that is, rock salt with subordinate beds of marl—which is 1327 ft. thick, and a lower saliferous group, which is 625 ft. thick, giving a total thickness of 1952 ft. of saliferous beds. The upper group was entered at a depth of 1141 ft. and the lower group at 3541 ft. There is rather more than 1000 ft. of marl between the two groups. Hitherto, the salt industry of Cheshire has been thought to draw its brine from one group of saliferous beds about 600 to 800 ft. thick, but it is now clear that there are two salt-bearing groups; the lower group is that exploited in the neighbourhood of Northwich and Winsford while the brine pumped around Sandbach and Middlewich appears to belong to the upper group.

The lower salt group extends beneath about 400 square miles and the upper salt group beneath about 170 square miles of the Cheshire Basin with, in each case, a further undefined extension southwards. The reserves of salt which would reasonably have been computed from previous information have been at least doubled; a provisional estimate of reserves now amounts to about 400,000 million tons, of which over 60 per cent is in the lower group.

The production of salt in the United Kingdom in 1957 was about 5 million tons. The chemical industry is a major user of salt in the form of brine for the production of soda-ash.

D.S.I.R. Report

Solar Energy

Solar energy can be harnessed by two methods: first, there is the direct method which corresponds basically to what physicists call the 'greenhouse effect', known to all horticulturists. The interior of the greenhouse heated by the sun's rays, reflects long infra-red waves to which the glass is opaque. The heat of these rays is caught as it were in a trap: it cannot escape, and tends to accumulate in the glassed-in space. This method, therefore, allows the sun's rays to enter through a glass surface and prevents the radiation of bodies heated by the sun from escaping.

The other method of harnessing the sun's energy is by concentration. This produces much higher temperatures than the direct method, where the thermometer rarely rises above 150° C. (300° F.)—practical working temperatures being located, for that matter, at a lower level between 60 and 80° C. (140° and 175° F.). Through concentration, temperatures can be obtained ranging from several hundred to several thousand degrees.

Two types of collectors are generally used. The 'flat' collector consisting basically of a dark plate, insulated on the side away from the sun, and protected from the wind on the side facing the sun by a transparent pane. The plate may heat either liquid-filled pipes attached to it or air. In general, it is mounted in a fixed inclined position which offers the best compromise for effective exposure to the sun.

The 'focusing collector' uses mirrors (or, exceptionally, lenses) in order to concentrate the sun's rays upon a small receiving object with a dark surface. According to the concentration obtained, this object can be heated to very high temperatures. In general, focusing collectors must be continually manoeuvred to follow the sun's movement.

The design and efficiency of the collectors have been improved in recent years by the use of new materials and of darkened selective surfaces with low radiating power. These selective surfaces reduce heat losses and thus make for better efficiency or higher operating temperatures. Glass, anodised aluminium and new plastics aluminised in a vacuum have been used for focusing collectors.

A third type of collector, suitable for very large surfaces, has been studied in France and in Israel. This is the 'solar pool', a shallow basin with a darkened bottom, whose operation is based upon the principle of water density. By dissolving salts in the water at the bottom of the pool, a very salty layer is obtained while the top layer remains un-salted, the difference in density preventing them from mixing. The top layer keeps an even temperature, because it loses its heat at the same

rate as it stores it, but the heat generated in the salty water at the bottom of the pool does not escape and it can be used as a source of power.

Elsewhere, work has been done on solar stoves, particularly in India and Mexico. These could be quite useful in areas where fuel is short.

Studies are also being made of machines for heating or cooling houses by solar energy. However, the problem is complex and results to date have not been conclusive. In France, refrigerators operating on solar energy have been perfected by the laboratory of Prof. Felix Trombe at Mont-Louis in the Pyrenees. They appear to be practical.

Mention should also be made of research aimed at converting solar rays into electricity through *thermocouples*—that is, without any mechanical process. Until fairly recently, solar converters using thermocouples were very inefficient and this form of conversion did not appear at all promising. However, prospects have become better in recent years thanks to improvements resulting from basic research in solid state physics. Progress in this field has been particularly noteworthy due to the work of Soviet, American, British and French scientists.

UNESCO

The Overseas Development Institute

Readers of *The Advancement of Science* may have noticed an announcement, which appeared in the Press in September, that a new Institute—the Overseas Development Institute (O.D.I.) had been formed to deal with development problems. The founders of the O.D.I. believe that there is need for a new institution which could serve as a centre to which all those interested in the problems of developing countries could turn for information about the needs of the latter and the action that is being taken to meet them.

Thousands of articles and books are being written about these problems; hundreds of different institutions, national and international, private and governmental, are trying to help developing countries in one way and another. But there exists no single office in the United Kingdom —nor, indeed, elsewhere—where information about all these various activities can readily be obtained. This is the hope of the O.D.I. that it will become such a central office of information on these subjects.

The O.D.I. will also try to serve as a centre in which those interested in particular aspects of the problems of developing countries can meet and exchange views. It seems to be a common experience that people dealing with the same problems in industrial or commercial undertakings, in government, or in academic institutions, are often unaware of each other's activities and thoughts. The O.D.I. hopes to be able to do something to fill this gap, and in addition it will seek to bring together those who are concerned with these problems in the United Kingdom and those who, in the developing countries themselves, have actual and intimate knowledge of them.

The O.D.I. will also have the task of keeping the public informed of what is going on in this field, of the needs of the developing countries, and of what the industrialised countries can and must do to help. To this end, it will use all the usual media of publicity and will, from time to time, through conferences, study groups, etc., try to stimulate the examination of particular problems and find new or better means of dealing with them.

The O.D.I. has been constituted as a Company limited by guarantee. It has a Council composed of distinguished representatives of many walks of life, of which the Chairman is Sir Leslie Rowan, K.C.B., C.V.O. The small permanent staff of the Institute is headed by a Director, Mr. William Clark, and an Associate Director, Mr. J. F. Cahan. Its offices are at 160 Piccadilly, London, W.1 (Telephone HYDe Park 2654). It is being financed by a grant of $200,000, to be made available over five years by the Ford Foundation and by contributions from industrial and commercial undertakings in the United Kingdom, for which an appeal is now being made. The O.D.I. does not contemplate a system of membership for individuals.

THE STRUCTURE OF THE UNIVERSE

By **Prof. H. BONDI, F.R.S.** *Professor of Applied Mathematics, King's College, London University*

The study of the structure of the universe is an important branch of modern science. The scientific nature of current investigations is in itself a marked achievement of relatively recent times. A subject can only be regarded as scientific if it satisfies certain criteria. The outstanding work of K. Popper on the method of scientific advance makes clear the relative positions of theory and experiment in cosmology as in any other scientific field. Theories are proposed by scientists to comprehend known facts but the crucial aspect of any theory is that it must make predictions that can be checked by future experiments and observations. A scientific theory is one that can be *disproved* by an appeal to experience. If the predictions of a theory are in agreement with experiments then the theory must be developed to make further predictions of experimental results. Thus no theory can ever be finally true in any sense, though naturally much confidence will be felt in any theory that has come successfully through numerous experimental tests. But unless a theory 'lives dangerously' by remaining vulnerable to further experimental work, it is not a scientific theory at all.

Cosmology, as the subject dealing with the structure of the universe as a whole is called, depends accordingly for its scientific character on the existence of the possibility of making relevant observations. These fall naturally into two classes:

(A) Attempts to gather information from so far away that the results are of cosmological interest. Our chief tools here are optical astronomy, using big telescopes, and radio astronomy.

(B) The study of local conditions crucially affected by the structure of the universe.

The existence of this second class is not immediately obvious, but a simple and important example is given by the paradox of Olbers. Olbers, a German astronomer, enquired some 130 years ago into the amount of background light of the sky that might be due to very distant stars. His line of thought was that if we pictured the universe as being uniformly populated with stars of more or less equal power of sending out light, then there should be a rather small number of stars close to us (so that we should see few very bright looking stars), rather more further away (i.e. a fair number of stars should appear to be of medium brightness) and a large number far away, leading us to see many faint stars. All this fits the facts, but what if we consider regions of the universe so far away that individual stars are too faint to be seen? Their number should be enormous, so it might be that their light would add up to give a background glow to the night sky, the intensity of which should give a clue about the structure of the universe.

To make a precise calculation, definite assumptions must be made about the distant parts of the universe. Olbers's assumptions (which, one would agree, were the most reasonable that could be made in his day) were as follows:

(i) The universe is, on the large scale, uniform in space.

(ii) The universe is, on the large scale, unchanging in time.

(iii) There are no major systematic motions of matter in the universe.

(iv) The results established by terrestial experiments are applicable throughout the universe.

Assumption (i) means essentially that the universe is uniformly populated with stars of definite average characteristics. Assumption (ii) is necessary, because, owing to the finite velocity of light, the radiation of distant stars reaching us now was emitted long ago and is thus determined by the number and brightness of these stars long ago. Assumption (iii) was made implicitly by Olbers as he could not conceive of an alternative. Assumption (iv) is clearly necessary for otherwise the door is wide open to an enormous variety of possibilities that can be chosen arbitrarily.

To consider the amount of light received from such a universe consider two spherical shells both centred on us, both of equal thickness, small compared with the radius of either, both so enormous as to contain vast numbers of stars, with the radius of the outer shell twice the radius of the inner shell. Therefore the area of the outer shell is four times the area of the inner one. Since the thicknesses are equal, the ratio of the volumes also is close to 4, and owing to assumptions (i) and (ii), there are thus four times as many stars in the outer shell as in the inner one. The light from any star in the outer shell has to travel twice as far to reach us as the light from any star in the inner shell and thus its intensity when received here will be only a quarter of that received from an equal star in the inner shell. Since there are four times as many stars in the outer shell as in the inner one, equal total amounts of light are received here from the two shells. This result is readily generalised to the statement that the amount of light received from a shell of given thickness is independent of its radius. Adding now the amounts of light received from all conceivable shells (infinite in number) we obtain an infinite amount of light. This absurd result requires some correction since each star not only sends out light to us, but also gets in the way of light from the more distant stars. A little calculation shows that, allowing for this obscuration, the total intensity of light received is finite and equal to about 50,000 times broad daylight.* In other words, if the universe were constructed in accordance with assumptions (i) to (iv), the situation here would be fantastically and unimaginably different from what it actually is. Therefore the observation that it is dark at night *disproves* the theory that the universe is constructed in accordance with assumptions (i) to (iv). (Although attempts have been made to reconcile the assumptions with the observations by supposing there to be absorbing material in space, or postulating a curved space, it can easily be seen that all such attempts are unsuccessful.)

A local observation, the darkness of the night sky, can therefore disprove an otherwise plausible cosmological theory. This shows both that cosmology is a science and that there are local conditions crucially affected by the structure of the universe.

There are other local phenomena of probably cosmic origin. The physicists are well aware of the fact that Maxwell's equations, which govern all electromagnetic phenomena, are symmetric in time and admit of moving charges emitting not only the familiar waves travelling forward in time, but also waves travelling backward in time which we have not found in nature. One of the most interesting recent theories of physics, the so-called absorber theory of Wheeler, Feynman and Hogarth, ascribes this local fact to the action of the universe as an absorber of radiation. This is closely associated with the darkness of the night sky previously referred to, and is likely to be directly responsible for one of the most elementary and deepest facts of experience, the direction of the flow of time. The very existence of the unique and sharp division of time into past, present and future may thus be due to the structure of the universe.

While the empirical refutation of Olbers's assumptions is one of the most important and fundamental achievements of cosmology, this branch of science has others to its credit. Before we can appreciate them, a brief outline has to be given of the results of astronomical observations. These show that the stars are gathered into vast agglomerations (containing up to several hundred thousand million stars) called galaxies, the majority of which are more or less flattened objects. Our solar system and all the naked eye stars (and most of those visible in telescopes) all lie in our galaxy which is highly flattened. As a result we see far more stars when we look along the plane of our

* Another way of arriving at this result is to consider that, on the basis of Olbers's assumptions, every line of sight will eventually intercept a piece of stellar surface. We are therefore wholly surrounded by stellar surfaces (on an average almost as bright as the solar surface) instead of seeing only the sun in an otherwise virtually empty sky.

galaxy than when we look in other directions. This profusion of stars in one plane is the Milky Way. Looking in other directions with powerful telescopes, vast numbers (many hundreds of millions) of other such galaxies can be seen. Outside the neighbourhood of the plane of our Milky Way (which is opaque to light from other galaxies) they appear to be uniformly distributed around us. Their distribution in depth, to the limited extent to which this can be explored, also seems to be uniform. There is thus direct observational support for Olbers's assumption (i). Next, if the mathematical question is investigated of how Olbers's assumption (iii) (No major systematic motions) can be dropped while sticking to the assumption of uniformity, it turns out that the only type of motion which keeps a uniform system uniform is one in which any two members are in relative motion along their line of sight with a velocity which is, roughly speaking, proportional to their distance apart. Thus the whole system is either in a state of uniform expansion or of uniform contraction. By studying the light of distant galaxies the astronomer finds that it is shifted to the red, and that this red shift is correlated with the apparent faintness of the galaxy. Effectively the only known physical reason for such a red shift is a velocity of recession. If the red shift is so interpreted, and if the apparent faintness of the object is taken to indicate its distance, then the velocity of recession so inferred is proportional to the distance of the galaxy. In other words, the only plausible interpretation of these observations is that the universe is in a state of expansion of the unique type compatible with the assumption of uniformity, lending yet more support to Olbers's assumption (i), while completely contradicting his assumption (iii). Moreover such a motion of expansion completely resolves Olbers's paradox. For a motion of recession, in addition to shifting the light to the red, also diminishes its intensity markedly. Thus the amount received from distant shells of stars is less than in our previous calculation, so much less indeed as readily to account for the darkness of the night sky.

While what has been said so far reflects the common background of virtually all present-day cosmological theories, the remainder of this paper will cover ground where there are rival theories and there are interesting and vital divisions of opinion. The chief point at issue is Olbers's assumption (ii), the unchanging nature of the universe. This assumption does not hold in the theory known as relativistic cosmology, whereas it forms the corner stone of the so-called steady-state theory. All these theories accept Olbers's assumption (i) (Uniformity of the universe) and the recession of the galaxies, thus dropping Olbers's assumption (iii). To take the steady-state theory first, its ideas are based on the following consideration:

In order to be able to apply our locally gained knowledge of physics to the universe at all times, we require Olbers's assumption (iv). In the light of the local effects of the structure of the universe, this assumption of the universal validity of the terrestrially discovered laws of physics is reasonable only if our position in the universe is *typical* in space and time. This is virtually equivalent to saying that the universe is, on the large scale, uniform in space and unchanging in time. Of course one does not say that the universe *must* be of this character, one only says that *if* it is of this character then it is possible to construct unambiguously a theory of cosmology which is vulnerable to empirical tests, and therefore this possibility should be explored first. If the universe is not of this character then one must contemplate laws of physics that change with place and time, which is an entirely possible but more complicated and therefore less vulnerable assumption which should thus be considered only if found necessary. On the basis of the steady-state theory, the observed recession of the galaxies is also an immediate deduction from the observed darkness of the night sky. However, we immediately run into a little problem. If the galaxies are receding from each other so that the spaces between them are increasing, then the mean density of matter would appear to be decreasing, contrary to our assumption of the unchanging nature of the universe. The only way out of this conundrum is to suppose that there operates a continual creation of matter at a rate exactly sufficient to counter-balance the depletion of matter due to the expansion of the universe. Owing to the low mean density and the long time scale of the universe this required rate of continual creation is very low by terrestrial standards (1 atom of hydrogen in 100,000 cu. ft. of space every 30,000 years or so) and is thus not susceptible to

direct observational test, although many consequences of this assumption are vulnerable. In order to keep the average age of galaxies unchanging, we have to suppose that the newly created matter forms diffuse clouds of hydrogen gas in the growing spaces between the galaxies, and then condenses to form new galaxies which themselves drift apart in the general cosmic motion as they age.

How can this theory be tested? There is a whole series of possible checks, only two of which can be mentioned here. One makes use of the fact that light takes a long time to reach us from distant galaxies (thousands of millions of years in the case of some galaxies observed). We see these galaxies therefore as they were long ago. If the universe were changing in any way then they should in some way differ in their general properties (colour, size, etc.) from near galaxies which we see as they are now. Any such systematic difference between distant and near galaxies would disprove the steady-state theory, and such tests are indeed feasible with existing equipment. Though highly recondite, work on these lines is proceeding.

Another test is based on entirely different considerations. Hydrogen is not only the simplest of all materials but far and away the most common one. While it has long been known that ordinary stars convert hydrogen into helium, it has also been thought likely by most physicists for 30 years or more that the small (1–2%) admixture of heavier elements must similarly have been synthesised from hydrogen. However, for a long time it was believed that there was no place in the present universe in which conditions existed that enabled the transmutation of hydrogen into heavier elements to take place. It was thus thought that the heavy elements were a relic, or fossil remainder, of an early and utterly different state of the universe, and therefore direct evidence for a change in the universe. This cannot be reconciled with the steady-state theory according to which, if ever there existed factories for making heavy elements out of hydrogen, then there must now exist such factories. This consideration led to investigations of Cameron, Hoyle, Fowler, Salpeter and the Burbidges which were brilliantly successful not only in proving that certain types of stars were such factories and that they eventually exploded and thus distributed the heavy elements generated, but also in showing that this process would lead precisely to the relative abundance of the elements found in fact. Thus the existence and distribution of the heavy elements now fits in perfectly with the steady-state theory instead of contradicting it, as was thought to be the case not long ago.

The alternative (and older) point of view* sticks to the usual inference from terrestrial experiments that matter is absolutely conserved. Of course the experiments only show that such conservation holds within their limits of accuracy, but then the simplest formulation of these results would seem to be absolute conservation and thus a denial of the continual creation demanded by the steady-state theory. It is clear that without such continual creation the recession of the galaxies implies a diminution in the mean density of matter in the universe and thus a change in the character of the universe, an *evolution* of the cosmos as a whole. It should be said here that all theories agree that there is an evolution of the individual constituent parts of the universe, the galaxies, each of which ages in the course of time. However, the picture given by the steady-state theory of the continual birth of new galaxies (by condensation of the newly created intergalactic matter), together with the thinning out of galaxies by the process of expansion, ensures that the average age of the galaxies in any region stays constant in time, so that there is no evolution of the universe on this theory. In the evolutionary models, on the other hand, not only the individual constituents, but the whole system undergoes change.

The best description we have of the behaviour of matter in the large (including its conservation) is Einstein's general theory of relativity. If this is applied to a uniform universe it results in the body of theory known as relativistic cosmology. This comprises numerous models of expanding evolving universes, the most famous of which is that due to Lemaitre. In this model the universe, finite but unbounded, started in a dense but highly condensed state, expanded rapidly at first, then, in middle age, very slowly (the period when the galaxies were

* The steady-state theory was proposed by Gold and the writer in 1948 and, in a different version, by Hoyle in 1949.

formed), and finally entered a renewed stage of expansion (its old age) in which we find ourselves. Perhaps the most crucial test of this theory concerns the ages of the galaxies. When theoretical astrophysics has advanced sufficiently to date a galaxy from its appearance then it should be possible to decide whether all galaxies originated at more or less the same time (as Lemaitre's theory demands) or whether there is a cross-section of all ages in accord with the steady-state theory.

It is impossible to recount here all the possible tests of current theories but it will be realised that in cosmology no less than in other branches of science the appeal to experience is fundamental.

NON-AUDITORY EFFECTS OF NOISE

By D. E. BROADBENT *Director, M.R.C. Applied Psychology Research Unit, Cambridge*

It is a curious feature of the study of human behaviour that some parts of the field arouse very strong emotions. The general public take little interest in the fascinating problems of retroactive inhibition (that is, the forgetting of one thing because you have since learned another). But topics such as hypnosis, subliminal advertising, or the use of punishment to control behaviour, are always sure to elicit vigorous opinions. Amongst these emotional topics is the question of the effects of noise on man. Many people in industry and the Services, who have practical experience of noise, regard any investigation of this question as a waste of time; they are not prepared even to admit the possibility that noise affects people. On the other hand, those who dislike noise will sometimes use most inadequate evidence to support their pleas for a quieter society. This is a pity, because noise abatement is really a good cause, and it is likely to be discredited if it gets associated with bad science.

One allegation often made is that noise produces mental illness. A recent article in a weekly newspaper, for instance, was headed with a striking illustration of a lady in a state of considerable distress, with the caption 'She was yet another victim, reduced to a screaming wreck'. On turning eagerly to the text, one learns that the lady was a typist who found the sound of the office typewriters worried her more and more until eventually she had to go into a mental hospital. Now the snag in this sort of anecdote is of course that one cannot distinguish cause and effect. Was the noise a cause of the illness, or were the complaints about noise merely a symptom? Another patient might equally well complain that her neighbours were combining to slander her and persecute her, and yet one might be cautious about believing this statement. What is needed in the case of noise is a study of large numbers of people living under noisy conditions, to see whether they are mentally ill more often than other people are. The United States Navy, for instance, recently examined a very large number of men working on aircraft carriers: the study was known as Project 'Anehin'. It is unpleasant to live even several miles from an aerodrome: if you think what it would be like to share the deck of a ship with several squadrons of jet aircraft, you will realise that a modern navy is a good place to study noise. But neither psychiatric interviews nor objective tests were able to show any effects upon these American sailors. This result merely confirms earlier American and British studies: if there is any effect of noise upon mental health it must be so small that present methods of psychiatric diagnosis cannot find it. That doesn't prove that it doesn't exist; but it does mean that noise is less dangerous than, say, being brought up in an orphanage—which really is a mental health hazard.

Another statement which is often made about noise is that it increases the amount of energy expenditure during work. This was said, for instance, in the same newspaper article I have already mentioned, and a very eminent physician was quoted to that effect. Now the experiment to which this belief is usually traceable is one by Laird performed about thirty years ago, in which the metabolic rate of four typists was measured with and without noise. It is less often pointed out that this experiment was criticised shortly afterwards by Harmon in the United States, on the grounds that the subjects were not given time to get used to the apparatus. In addition the mathematical analysis was not up to modern standards. Harmon himself carried out a more extensive study, in which metabolic rate was not found to be

greater in noise: and the same finding was reported by Vernon and Warner in this country. One need not be completely destructive about Laird's results however, because quite a number of people, and especially R. C. Davis of Indiana, have found that the first occurrence of a strange and unfamiliar noise will produce an increase in muscle tension and therefore presumably greater energy expenditure. There are also likely to be changes in heart rate, breathing, and the resistance of the skin. This pattern of bodily changes is of course familiar to many of us as the 'fight-or-flight' reaction which is liable to appear in any emergency, and whose purpose is presumably to prepare the body for violent exertion should that be necessary. Any unfamiliar situation, not just a noise, is likely to elicit similar responses, and if a noise is presented more than once the effect rapidly disappears. It is merely a response to novel conditions and vanishes in familiar ones: it cannot really be used as an argument against noise as such.

In recent years there has been a good deal of interest in studying more chronic responses to stressful conditions of all kinds: the activity of the adrenals for instance may become high when an animal or man is required to adjust to uncongenial surroundings, and if this response is elicited to excess there may be pathological changes in the glands. These changes are of course difficult to detect until after death, but the level of adrenal activity can be assessed to some extent by counting the number of eosinophil and sudanophil cells in the blood. By this latter means a group of researchers working for the U.S. Air Force at Wright Field have shown that rats exposed to extremely high intensities of noise do have higher adrenal activity, and so also do men even if they are used to noise. But the level of activity does not seem to be enough to be harmful: the amount produced in rats by noise is about the same as that produced by keeping two rats in the same cage rather than separately. The glands do not show pathological changes with sounds below 5000 c.p.s. even at intensities of 140 dB (decibels) for long periods. One point of some interest is that rats who have been exposed to noise show no sign of sexual inefficiency, which suggests that they had not been under excessive stress and also tends to cast doubt upon one of the beliefs sometimes associated with noise.

On the basis of the evidence mentioned so far, it is clear that physiological changes do take place in noise, and particularly at the onset of the sound. But there is no indication that these are harmful: they are of much the same kind as those produced by, for instance, being introduced to a strange member of the opposite sex. We might find ourselves in an awkward position if we use these changes as arguments for noise abatement, since we might have to forbid the other (and rather pleasant) things which produce the same effects.

There is however one effect of noise which seems to go on even when the noise is a familiar one: and that is constriction of the peripheral blood-vessels. This effect has perhaps been most emphasised by researches at Dortmund in Germany, but it is confirmed by results of R. C. Davis and also of Grandjean in Zürich. Both these workers have shown decreases in finger volume during noise, which do not seem to adapt as much as other responses do. The meaning of these findings is not at all clear: but Jansen of Dortmund has examined clinically a thousand German steel workers and found that those who work in high noise levels have a significantly higher incidence of paleness of the skin; and of abnormal heart rhythm. They also more often report peculiar sensations in hands and feet. One ought to emphasise that these are all rather difficult symptoms to pin down, and also that men who work in noise usually have jobs which are odd in other ways: they tend to be pneumatic drill operators rather than clerks, for instance. But there is at least a possibility that noise may produce circulatory changes. It was reported earlier by Halstead of Chicago that a small group of jet aircraft workers were inferior at fitting shapes into holes by touch, and this may be a related effect.

If then bodily changes are rather disappointing as evidence against noise, what about the efficiency of work? Typists are often said to work less well in a noisy office. The evidence in this case is usually taken from the Aetna Life Insurance Company's investigation before the war. It is not usually pointed out however that, although the typists studied in that case did do better when their room was quietened, they went on doing well when the noise level was subsequently returned to its original value. In the same way it was found by myself and Little that the operators of photographic

perforating machines worked faster after the introduction of acoustic treatment: but they did so just as much when they were working in rooms which had no treatment in at all. It is in fact possible to work wonders by suggestion, and by the improvement of morale which results from taking an interest in the conditions of the men you employ. Nobody has ever shown satisfactorily an effect on efficiency from noises of the intensity of the ordinary office. At higher intensities there is however a real effect, which takes the form of making mistakes or failing to notice some unexpected event. In the photographic perforating work, for instance, it took the form of breaking the film: and it has appeared now in a large number of laboratory studies both here and in America. It can be thought of, crudely, as some sort of temporary interruption of the sensory pathways due to the intense competing stimulus. Such an interruption is now quite respectable physiologically, since in the last few years a great deal of attention has been paid to the role of efferent nerve fibres running out from the brain to the sense organs and possibly controlling their sensitivity. One thinks, for instance, of the well-known demonstration by Hernandez-Peon and his associates: if a click is made into a cat's ear, an electrical response can be picked up from the auditory pathway. But if the cat is shown a mouse, the electrical response to the click disappears. It is perhaps a little dangerous to adopt the simple interpretation that the sight of the mouse turns off the cat's ears, and even more dangerous to suppose that hearing a noise turns off a man's eyes. Some of the psychological experiments are not consistent with such a view: U.S. Air Force experiments have suggested for instance that the effect is less serious when a man is keeping his attention on one job, than it is when he has to shift attention between several jobs. If I may be pardoned a psychologist's statement of faith, we must be sure what the characteristics of behaviour are before we can put forward physiological explanations for them. As yet, all we can say is that there is this effect on working efficiency, that it is in some cases of practical importance, but that it only appears at the sort of noise levels where deafness is in any case likely to be produced by the noise.

Finally, what about annoyance? One must be clear that the unpleasantness of a noise has nothing necessarily to do with its harmfulness. There was a view current amongst psychologists some time ago that ultimately behaviour was based only upon the satisfaction of physiological needs, but this is not now generally accepted. One can, for instance, get a rat to learn the solution to some problem by giving him saccharin every time he does it right. The saccharin does him no good: he just likes it. Equally if one makes a sufficiently loud noise at him, it may do him no harm: but if he can, he will go away. There are in fact certain types of stimuli which animals and men tend to approach, and others which they tend to avoid. By and large these stimuli are such that the behaviour is adaptive, but they need not do any direct good or harm to the organism. Now if a noise is loud enough, people do try and avoid it. You can make a man work more accurately in a laboratory situation by arranging that he gets a loud blast of noise for every mistake; it is much more effective than just telling him about them. Of course, he may avoid coming back for the next experiment: but even that shows the reality of the tendency to keep away from high intensity sounds. Similarly if the noise from aircraft exceeds a level of 100 dB above the threshold of hearing, almost everybody will complain of it. Most people will object more if the noise is irregular, and if it is high-pitched, than if it is steady and low-pitched.

It is not enough however to say that people have a natural antipathy to noise which makes them take actions designed to reduce it. When sounds are relatively faint, some people still dislike them even though most people are perfectly happy about them. Aircraft noise at a level less than that of my voice will still produce complaints from some people though not from most, and practically every individual has some faint sound which he dislikes intensely: the sucking of teeth perhaps, or the dripping of a tap. It is worth remembering that even in animals a neutral stimulus can become one to be sought or avoided, if it is often given with a reward or a punishment. A rat will not bother to learn to undo a latch merely to escape from a certain room; unless it has been shocked in that room, in which case it wants to avoid even the sight of the room. Similarly it seems likely that each individual human being does associate certain sounds, or sights, with the anxiety-producing situations in which they have been met. When

aircraft noise was slightly less intense than it is now, a few years ago, it was shown by a social survey technique that a very high proportion of the people who complained of noise were in fact frightened of aeroplanes. This may not be so true at modern intensities, but it illustrates the principle. Furthermore one might expect that people who are anxious in a good many situations will tend equally to acquire a dislike for a number of noises: and it has indeed been shown by several investigations that people who have difficulties in personal adjustment to life do complain more of noise than more stable individuals do.

In so far then as particular noises are annoying because of individual experience, we can never hope to remove annoyance completely. But the proportion of people annoyed does drop as the intensity is reduced, and it is therefore worth practising noise abatement even though one cannot abolish annoyance completely. You may well ask, why should we worry about annoyance for noises below 90 dB or so which probably do not affect our health and efficiency? I can only reply by giving what might be called a behaviourist's definition of civilisation: a way of organising society so as to increase the number of stimuli which are approached, and to decrease the number of those which are avoided. The real effects of loud noise are quite enough to worry about, without creating myths as well: but in any case there is nothing disreputable about reducing noise simply because people do not like it.

Further General Reading

Broadbent, D. E. (1957): 'Effects of noise on behaviour', *Handbook of Noise Control* (ed. C. M. Harris), McGraw Hill, New York.

Kryter, K. D. (1950): 'The effects of noise on man', *J. Speech Hearing Dis. Monog. Suppl.* 1.

Some More Recent Technical Papers

Anthony, A., Ackerman, E., & Lloyd, J. A. (1959): 'Noise stress in laboratory rodents', *J. Acoust. Soc. Amer.* **31,** 1430–7.

Broadbent, D. E., & Little, E. A. J. (1960): 'Effects of noise reduction in a work situation', *Occup. Psychol.* **24,** 113–40.

Davis, H. (ed.) (1958): Project 'Anehin'. Report No. 7, Joint Project NM130199 Subtask 1, Central Institute for the Deaf and U.S.N. School of Aviation Medicine.

Davis, R. C., Buchwald, A. M., & Frankman, R. W. (1955): 'Autonomic and muscular responses and their relation to simple stimuly', *Psychol. Monog.* No. 405.

Jansen, G. (1959). 'Zur Entstehung vegetativer Funktionsstörungen durch Larmeinwirkung', *Archiv für Gewerbepathologie und Gewerbehygiene,* **17,** 238–61.

Jerison, H. J. (1957): 'Performance on a simple vigilance task in noise and quiet', *J. Acoust. Soc. Amer.* **29,** 1163–5.

OCEANOGRAPHY IN THE INTERNATIONAL GEOPHYSICAL YEAR

By Dr. G. E. R. DEACON, C.B.E., F.R.S. *Director, National Institute of Oceanography*

The main idea of the International Geophysical Year was to co-operate in studies that need world-wide networks of observations. Oceanographers exploited the idea by studying changes in mean sea level which affect whole oceans, long waves that travel right across oceans, and the general circulation of water, also ocean-wide in character.

Mean Sea Level

Mean sea level is not the unalterable datum often implied in everyday usage. As scientific measurements become more accurate and continuous and engineering practice more refined, we often find that the simple concepts that have served for many years are no longer adequate. This is specially true of our knowledge of the earth and sea. For example, more accurate levelling and the need for cheaper and more effective coastal defences make us take notice of changes in sea and land levels. It is not a new idea. Sir John Lubbock, asking for more careful study of the tides at the very first meeting of the British Association, remarked that M. Daussy, measuring tides at Brest, had shown that the atmospheric pressure has a considerable influence on the height of the tide: an inch rise of the mercurial column depressed the tide 14 in. Lubbock himself soon found similar changes. A rise of 1 in. of the barometer caused a depression in the height of high water of 7 in. at London, 11 in. at Liverpool and 13½ in. at Bristol. Sir James Clark Ross, measuring tides at places as far apart as Tasmania and the Canadian Arctic in the 1840s, found that the ocean behaved like a water-barometer on a vast scale of magnificence. Interest was at first confined mainly to the effect of pressure and wind on the tides, but it was soon widened by the study of fluctuations and trends in average conditions from month to month and year to year. In studying variations of such long duration the effects of changing temperature and density had also to be taken into account.

For the past 30 years the International Association of Physical Oceanography has had a Committee on Mean Sea Level and has published tables of monthly and annual mean heights of sea level calculated for seaports all over the world, many of the records going back well into the nineteenth century. The first list was edited by Professor Proudman when he was Professor of Oceanography at Liverpool University, and the most recent one —for the I.G.Y.—was issued by the Liverpool Tidal Institute, now the international centre for data on mean sea level, only a few months ago.

Using these data, Patullo, Munk, Revelle and Strong (1955) showed that sea level is usually lower in spring than in autumn, and that the range varies from a few centimetres at island stations in low latitudes to 165 cm. in the Bay of Bengal. Changes in mean atmospheric pressure were found to account for only a part of the monthly variations; changes in volume of water, especially those due to variations of temperature, usually account for most of the difference. Near the British Isles the mean sea level is about 15 to 20 cm. higher in autumn than it is in spring. Most of it can be accounted for by differences of temperature and pressure, but there is also evidence that there is less water in the ocean at the end of winter, probably because more of it is stored on land.

The fluctuations in mean annual level from year to year are usually less than ±5 cm. but can be as much as ±10 cm. They seem to be attributable mainly to changes in climate. Except in high latitudes, they show a slow upward trend, and during the past 50 years mean sea level round

southern England has risen nearly 7·5 cm. This corresponds to an average rate of about 15 cm. or 6 in. in 100 years. The main factors seem to be the melting of continental ice and warming of the ocean, but uplift and subsidence of the land add to the complexity of the problem. In the northern part of Finland the land has been rising relative to the sea at a rate of about 1 m. in 100 years. In the southern part of the country the rate is much less, and in some of the long north–south lakes the effect of tilting is readily apparent. The rise in sea level in Scotland seems to be appreciably less than it is in the south of England. At Churchill on Hudson's Bay the rate of uplift seems to be about 2 m. in 100 years. Examination of such observations and historic evidence leave no doubt that the rising of the land in such areas is due to its recovery and readjustment after the melting of the great load of ice that it carried during the last glacial period. A number of estimates of the absolute rise of water level, based mainly on measurements from countries where post-glacial uplift is not so likely, suggest a rise of about 11 cm. in 100 years, a little over 4 in. This figure is, however, rather uncertain. In addition to this major effect there are also local risings and sinkings due to changes in the water content of the subsoil, building and other loads. At a rate of 6 in. in 100 years the rise of sea level relative to the land begins to be important in practical problems of coastal protection, as well as demonstrating the need for better understanding of what goes on in the sea and the earth's crust.

There are changes from place to place as well as from time to time. The best known example is the difference in mean sea level between the two ends of the Panama Canal. In the rainy season the mean level at the Pacific end is 30 cm. higher than that at the Atlantic end. In the driest month there is not much difference in level, but on an average, throughout the year, the level at the Pacific end is 21 cm. higher. The question is sometimes asked: how such a difference can be maintained while the oceans are joined round Cape Horn? The answer is that the difference represents equilibrium conditions. There is a tendency for the combined pressure due to weight of air and water to be uniformly distributed over the ocean, the sort of equilibrium that geologists call Isostatic, and to get the same pressure or weight of water needs a slightly higher column where the water is warmer or less salt. It is not quite as simple as this because there must also be dynamic equilibrium between the distribution of mass and the forces that drive and control the water movements. The effect of the earth's rotation makes the water level higher on the right-hand side of a current in the northern hemisphere: mean sea level on the French side of the Straits of Dover is 1 or 2 cm. higher than it is on the English side because of the effect of the earth's rotation on a slow overall movement from the English Channel to the North Sea.

During the I.G.Y. some sixty new tide gauges were installed, the sites being chosen to obtain better cover of the world oceans, and where possible island locations were chosen. In the open ocean the seasonal changes appear to be explained mainly by seasonal contraction and expansion of the water, variations in atmospheric pressure and migration of currents. More complex changes occur along continental coastlines, where the effects of wind, currents and drainage from the land are considerable. The variations along the coastlines of the continents are generally greater than those offshore. The I.G.Y. programme has stimulated greater interest and encouraged geodesists, who study the shape of the earth's crust, to co-operate with oceanographers, who study the sea. This co-operation was of course inevitable. Miss Patullo comments that geodesists who have hopefully used 'sea level' as a reference and oceanographers who, equally hopefully, have used 'fixed bench marks' have finally bumped into one another going backwards.

Long Waves

Every now and then serious loss and damage are caused by unexpected long waves which are like tides rather than ordinary sea waves, and for this reason called tidal waves. They are not, however, caused by the attractive forces of the moon and sun, and not repeated regularly like the tides. Instead their energy comes from occasional disturbances at the sea surface and bottom, from intense storms and submarine earthquakes. The names 'storm surge' and 'seismic surge' are more appropriate, but the Japanese name 'tsunami' is the one most used for the waves produced by a submarine earthquake.

A disturbance of the sea floor generally affects an area whose dimensions are fairly large compared with the depth of water and most of the energy goes into waves whose length, between successive crests or troughs, is long compared with the depth of water. The speed of propagation of such waves is controlled by the depth of water. It can be shown theoretically that it is approximately $\sqrt{(gh)}$, where g is the acceleration due to gravity and h the depth of water, and since most of the deep ocean has depths between 3000 and 6000 m. the long waves travel across them at speeds between 400 and 550 miles per hour. This is, of course, the speed of the wave, not of the water particles in it. In deep water the water moves only a few feet, forwards and upwards with the crest of the wave and backwards and downwards in the trough. A large disturbance is likely to send a group of five or six waves, and in deep water they are likely to be not more than 1 or 2 ft. high with as much as 100 miles between successive crests. They will not be noticed by ships outside coastal waters. It is only when they move into shallow water that their speed decreases and height increases so that a long wave 2 ft. high in deep water may be amplified to 20 ft. by the time it reaches the shore, and to much greater heights in a bay of the right shape and size.

One of the worst catastrophes of recent years started with a submarine earthquake near the Aleutian Islands on April 1, 1946. Four and a half hours later the first wave reached Hawaii causing great loss of life and damage. At Valparaiso the waves were still 5 ft. high and in the Antarctic they were large enough to wash away an old hut left by the British Graham Land Expedition. After the disaster at Hawaii a warning system was started. Seismograph reports are sent to a central observatory in Hawaii and if the epicentre of the earthquake seems to be at a place where it is likely to cause a sea wave tide-recording stations are warned, and the information they give is used to prepare a prediction for the rest of the ocean. The system worked very well, but the tragic consequences of the waves which swept across the ocean from the Chilean earthquake on May 23, 1960, show that there is still much to do. The times of arrival at places as far distant as Hawaii and Japan were predicted almost to the minute, but the warnings issued by the local authorities were not fully heeded. The death roll in Japan was more than 100. People soon forget disasters, but seem to remember warnings that have perhaps erred on the side of caution. It is very difficult indeed to make a forecast for every part of a coast. The size of the wave and the violence with which it runs on to the land depend very much on the direction of approach, offshore bottom topography, width of protecting reefs and other factors. Some parts of Hawaii did not know about the 1946 waves till they learnt of the damage to other parts of the coast not far away. Some places on the coast of Japan experienced a very high wave after the Chilean earthquake, while at others it was barely noticeable. The recent disaster has renewed the demands for research and will lead to improvements in the warning system. When the sea has been disturbed on such a scale it takes many days to settle down. On the west coast of Hawaii some waves came in 18 hrs. after those that damaged the north coast, and it is presumed they arrived after reflection from submarine slopes or land in the western part of the ocean. The worst effects occur where there is a bay or fjord with dimensions that make it resonate with the oncoming waves as well as concentrating the energy in a sort of funnel. In such places the water can swash over the end like the water from a bath and there are records of great waves making clean sweeps of forest round inlets in southern Alaska. One of them went up to 1700 ft.

In the United Kingdom we have escaped serious earthquake waves, but not waves energised by atmospheric disturbances. The serious floods of January 1953 were due mainly to a long surge travelling down the east coast and round the southern part of the North Sea to the coasts of Holland and Germany. The height of the surge seems to have been due mainly to the piling up of the relatively shallow water of the North Sea before the strong north wind. Flooding on our west coasts seems to be more dynamic in origin. Any disturbance moving fast over the sea tends to make a wave, and if the disturbance travels at a speed which approximates to the speed of a free wave in that depth of water there is a near-resonance effect, and the wave, receiving energy all the time, grows large. Winds and pressure disturbances do not travel fast enough to excite such resonance in the deep ocean, but they can do it over shallow

water. The disastrous storm surges on the east coasts of the United States and Japan are produced in this way. On a small scale the effect is sometimes seen in the English Channel. A travelling change in pressure or wind may be too small to be noticeable, but if it travels at the right speed it produces a wave that will make the water rise and fall several feet in as many minutes. These have often caused considerable confusion on beaches and among moored boats.

During the I.G.Y., long-wave recorders were installed on many oceanic islands as well as on continental margins. There were no large seismic or storm surges, but much has been learnt from studies of the low background oscillations that are always present. Every body of water has its own natural modes and periods of oscillation, and spectral analysis of the long-wave records indicates that resonant amplification of natural periods determined by the depths and topography of the shallowing water are more important than simple amplification as the energy is concentrated in a smaller water column. The natural periods of oscillation generally fall between 1 and 25 min. and they seem to be maintained at a low level, probably by coupling with atmospheric oscillations. U.S. scientists report characteristic oscillations of 6 to 8 min. period on the S.E. coast of Bermuda, 8 to 10 min. on the south coast of Terceira in the Azores, and 16 min. on the south coast of Iceland. Under quiet conditions they have an amplitude of 1 to 2 cm. If excited by earthquake waves they might be 1000 times as large. Comparison of coastal recordings with those taken at Texas Towers in the relatively open ocean indicate that the coastal region has much more activity in the shorter, 1 to 3 min., range. These shorter oscillations seem to result from varying transport and acceleration in groups of high and low waves as they run on to shelving beaches. They are called surf beats and appear to be one of the main sources of energy for the troublesome oscillations, known as range action, which often occur in harbours built on exposed coasts.

The I.G.Y. observations have added very much to the interest and growth of the subject.

Ocean Circulation

After 150 years of ocean exploration we have sufficient observations of the temperature and salinity at all depths in most parts of the oceans to give a general idea of movements of water that can be followed from the spreading of distinctive properties. One of the most remarkable deep currents starts in the colder part of the North Atlantic Ocean mainly between Greenland and Labrador, where cold water with a fairly high salt content sinks and spreads southwards mainly between depths of 2000 and 3000 m. On the way south it is joined by highly saline water flowing as an undercurrent from the Mediterranean Sea. The combined flow keeps its deep level as far as about 50° S. and then climbs to a much lesser depth, above a large wedge of Antarctic bottom water and below a shallow layer of Antarctic surface water. It feeds these two layers: the surface layer shows it diluted as well as cooled, and in the bottom layer it has been cooled under rather special conditions without much dilution. The position of the highly saline layer, sandwiched between less saline layers, gives unmistakable evidence that it is fed from the north. In the circumpolar ring of ocean round the Antarctic continent it gets mixed with deep water of somewhat similar properties from the other oceans, but because of its high salinity it can be traced round the Cape of Good Hope into the Indian Ocean, and south of Australia into the Pacific Ocean. The Antarctic surface water sinks below the surface in about 50° S. and can then be traced as an intermediate layer, between the deep current and warmer and more saline surface and subsurface waters, well into the North Atlantic Ocean. The bottom current also can be traced as far as 40 to 50° N.

Although very slow, these movements transport large amounts of water and heat from one end of the ocean to the other and have a considerable effect on its mechanics and productivity. During the I.G.Y. further detailed studies were made. The first objective was to try to see what changes had taken place since about 1925–7, when the Atlantic Ocean was extensively studied by the German 'Meteor' Expedition; the second was to improve our knowledge of water exchanges between the Arctic and Atlantic Oceans, and the third to supplement the qualitative information by direct measurements of the deep currents. Many observations were made and it will be some time before the detailed study is complete; as far as we can

see at present the water conditions in the deep layers have not changed much.

The deep-current measurements have already given new information. Although we already knew something about the spread of the deep water we knew little about the rates of flow. Older estimates based on the little we knew about rates of mixing, and attempts to use inadequate data to follow water which had left the surface in different seasons, suggested average speeds of about 1 mile a day. More recent work based on changes in the ratio of carbon isotopes, and very questionable assumptions about surface equilibrium and history of the water, suggested speeds at least a hundred times as slow. Actual measurements made with current meters suspended on long wires below ships anchored with very long cables did not help very much because the movement to be measured is small in comparison with the tidal streams and with the errors that are to be expected from the movements of the ship about its mooring.

The best thing to do was to make a float that would drift with the deep current while giving signals that could be received and plotted by a ship on the surface. Dr. Swallow of the National Institute of Oceanography made one very simply with aluminium scaffold tubing. When sealed at the end this tube is less compressible than sea-water. When loaded with batteries and a simple circuit and magneto-striction oscillator to produce the sound signals, his float is just heavy enough to sink below the surface. As it goes down it is compressed by the pressure of the water, but its decrease in volume and increase in density is not as much as that of the surrounding water. As the float sinks into denser water it gains buoyancy, and according to the weights added before sending it down it can be made to float at any predetermined depth. When down there it drifts with the current and signals its position. Nearly a hundred floats at depths ranging from 500 to 5000 m. have been followed for an average of about 4 days each (the longest for 48 days) and enough temperature and salinity observations have been made to attempt to relate the currents to the density distribution and events in the atmosphere. At all depths the currents have proved faster and more variable than was expected. Their speeds have varied mainly between 1 and 5 miles a day, but there are some notable exceptions. A southward counter-current below the Gulf Stream was observed to flow at $\frac{1}{3}$ knot, water at a depth of $2\frac{1}{2}$ miles north-east of Bermuda moved northwards for several days at nearly 1 knot, and U.S. scientists have found an equatorial subsurface current in the Pacific Ocean flowing at $2\frac{1}{2}$ knots.

In this work as well as in studies of mean sea level and long waves the I.G.Y. observations have brought to light more problems than they have solved, but they have given a new realistic picture and show us how to go on.

The I.G.Y. was undoubtedly a success and it has led to other co-operative schemes. These are very promising, and they need more and more support from pioneering research by individuals and small groups. Perhaps some of the new organisation does not give enough help in this direction. The I.G.Y. data centres, for example, must develop along more liberal lines. Busy scientists cannot be expected to negotiate about the cost of copying data, or to fill up forms to get foreign exchange and to pay bills before they can see what they are buying. The old-fashioned muddle of personal exchanges between men actually doing the work was really more effective.

Reference

Patullo, J., Munk, W., Revelle, R. & Strong, E. (1955): 'The seasonal oscillation in sea level', *J. Mar. Res.* **14**, 88–156.

THE GEOGRAPHICAL VARIATIONS OF DISEASE MORTALITY IN ENGLAND AND WALES IN THE MID-TWENTIETH CENTURY

By Dr. G. MELVYN HOWE *Department of Geography and Anthropology, University College, Aberystwyth*

INTRODUCTION

Disease may be looked upon as the reaction for the worse between individual man and adverse factors of the environment.[1] Modern geography concerns itself with studying and interpreting the mutual relationships of Man and his environment. There is thus a common field of study between medicine and geography for which a number of names have been coined—medical geography, geomedicine, medical ecology, geographical pathology, or the geography of disease.

Medical men have not been unmindful of the influence of climate, terrain, vegetation and demographic features on the spread of communicable diseases, as instanced by the classical monograph of A. Hirsch.[2] But interest in this approach has tended to lapse over the last fifty years or so. Now, however, the idea that the secrets of disease may be unfolded by the geographical approach is once again gaining ground.

What is the geographical approach to the study of disease? First, it involves mapping the geographical distribution of disease—of either disease mortality or disease morbidity—since a map is the most efficient means of demonstrating distributions in space. Distributional patterns are then described and analysed. Finally, possible direct or indirect relationships between the distribution of disease incidence and factors of the environment —physical, cultural or both—are searched for and demonstrated, with the object of providing clues or pointers to possible lines of research in the causation of disease.

The geographical method is seen at its best where the data are fully available and the ground accessible to study. What better, therefore, than to select England and Wales as the study area? With 44 million people—81 per cent urban and 19 per cent rural—crowded on to 58,000 square miles,[3] England and Wales together present an amazing variety of environmental conditions within small compass. Even so, a broad dichotomy or dualism can be recognised, the dividing line following an irregular course from the mouth of the River Tees in the north-east to the mouth of the River Exe in the south-west. West and north of the line lies the Highland Zone; east and south the Lowland Zone (these Zones are shown in Fig. 7). In the Highland Zone are found the major mountain and hill masses of Britain. These cool, humid, wind-swept and water-logged uplands with thin and generally acid (lime-deficient) soils contrast markedly with conditions to the south and east. Here, the land surface is seldom more than a few hundred feet above sea-level, is far more subdued and comprises broad plains, low-lying plateaux and scarplands. Conditions on these younger Mesozoic and Tertiary rocks of the Lowland Zone are, generally speaking, more favourable to human settlement than on the ancient Palaeozoic rocks of the Highland Zone. To this contrast in basic rock structure and relief can be related important differences in race, history, agriculture and industry.

The introduction of the comprehensive National Health Service in 1948 meant that medical and statistical facilities were extended to all classes of society with a high degree of equality. In addition, reliable death certificates are available. In the present study mortality data for the years 1950–3 were taken from the Registrar-General's Decennial Supplement entitled 'Area Mortality'.[4] All Metropolitan and County Boroughs and Administrative Counties have been considered and the data relates

to the populations of these same areas as enumerated at the 1951 Census. Three points, however, need mention before the disease distributions are examined.

(*a*) Standardised mortality ratios (S.M.R.) rather than crude deaths have been used for mapping. The S.M.R. makes allowance for differences in local age-structure of the population by a process of 'indirect standardisation' and, compared with the crude death rate, it is a much more reliable index. It is, in fact, the only satisfactory means of comparing the mortality in any local area with that of the country as a whole. If, for example, an area has an S.M.R. of 100, it means that for the period under consideration the area experienced a mortality rate similar to that of England and Wales taken as a whole. If the S.M.R. is 200, the mortality rate is twice as great as the national average—i.e. it has a very unfavourable mortality experience; if the S.M.R. is 50, it is half the national rate and obviously has a most favourable mortality experience.

(*b*) The maps are based on administrative rather than geographical divisions. Thus, while true regions of high, low or average mortality from a disease must certainly exist in the general areas enclosed by the administrative boundary lines, they are unlikely to be co-extensive with them.

(*c*) Since deaths are classified according to the area of usual residence of the deceased, the possibility of numbers of deaths for certain areas being appreciably affected by persons dying in hospitals located in those areas does not arise. The pattern of geographical distribution is thus unaffected by deaths in hospitals.

DISTRIBUTION MAPS

Reference to the relevant medical data reveals the four main causes of death in England and Wales in the mid-twentieth century—for both males and females—to be the heart diseases (e.g. coronary thrombosis), vascular lesions affecting the central nervous system (i.e. 'stroke' due to cerebral thrombosis or cerebral haemorrhage), cancer and bronchitis. The geographical distributions of mortality from these diseases (on the basis of standardised mortality ratios), for males only, are shown in Figs. 1–4 and Fig. 6, and a synthesis, for both males and females combined, on the basis of areas with very high death rates from 'all causes', and areas with very low death rates from 'all causes', is given in Fig. 7.

1. Arteriosclerotic Heart Disease, including Coronary Disease

The distribution of deaths from this cause shows areas of very high rates in the north of England (Fig. 1). Rates in Cumberland, Westmorland, Northumberland, the North Riding of Yorkshire, Lancashire and Flint are over 10 per cent more than the national average. On the other hand, areas with the more favourable mortality experience for this disease are to be found in a discontinuous zone extending from west to east across Wales and England from West Wales and the Welsh Borderland, through Stafford, Oxford and Huntingdon to Lincoln (Holland) and Norfolk. It is of interest to observe in this context that for both males and females there is an urban/rural gradient of mortality, the highest rates being in the big urban areas (e.g. Southport, S.M.R. 149; Halifax, S.M.R. 133; Cardiff, S.M.R. 130) followed by the middle-sized towns and the rural districts.

Investigations by the Medical Research Council[5] suggest that men in sedentary occupations involving a certain amount of nervous strain are more liable to get coronary thrombosis in middle life than men engaged in physical labour involving regular exercise. It seems unlikely, however, that the men of places like Southport, Halifax or Cardiff, with S.M.R.s 30–50 per cent above the national average, do less manual work than those of places like Dudley (S.M.R. 67), West Bromwich (S.M.R. 74) or Walsall (S.M.R. 78). On the other hand, it should be appreciated that Fig. 2 shows mortality from *all* heart diseases, and not only coronary thrombosis. Even so, one is left wondering just what aspect or aspects of the physical or cultural environment of the areas with high mortality rates accounts for such a distributional pattern?

2. Vascular Lesions affecting the Central Nervous System

These circulatory diseases—cerebral thrombosis or cerebral haemorrhage—are the so-called 'strokes' of the layman. North and west of an irregular line from Hull to Cardiff the S.M.R.s

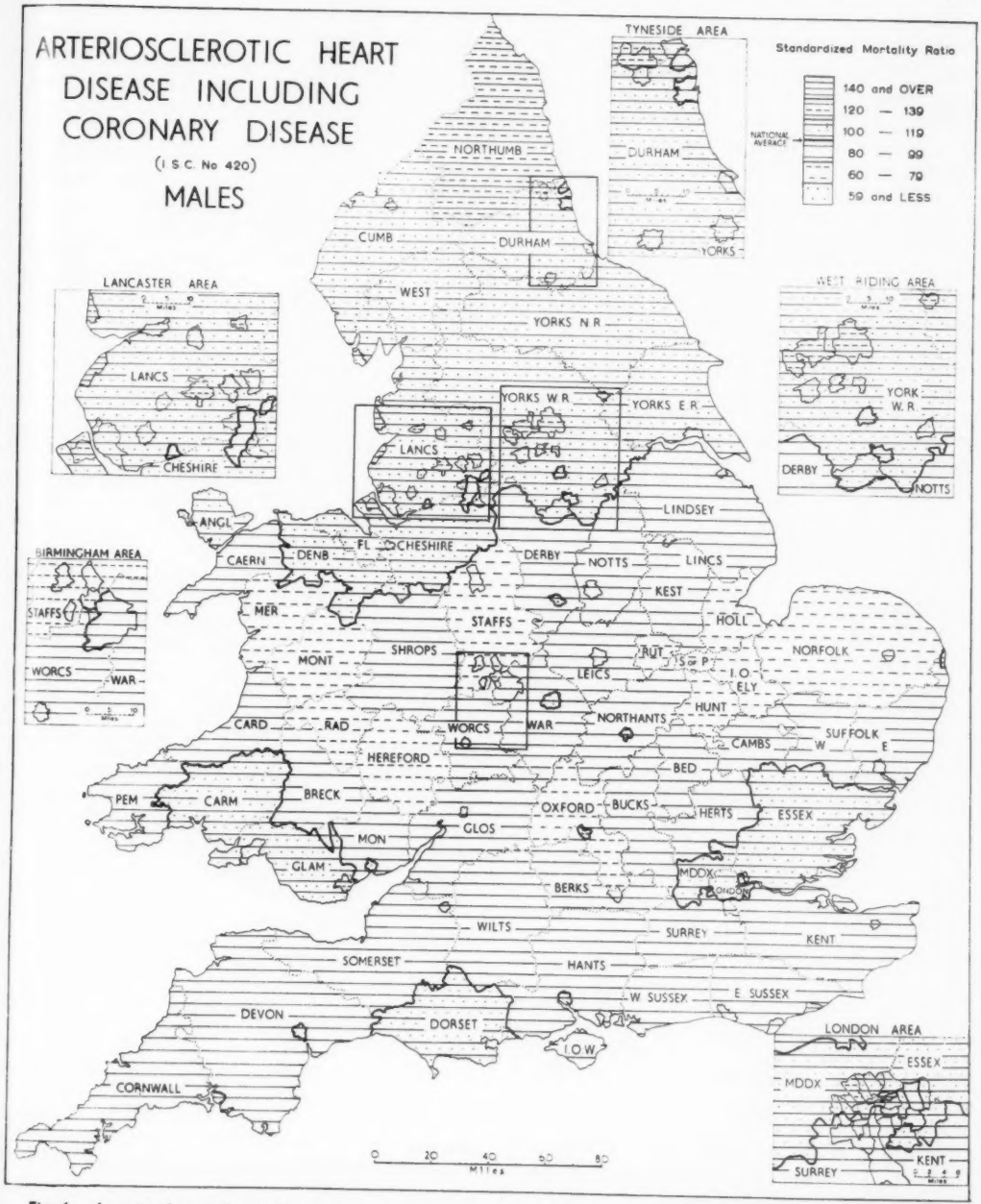


Fig. 1.—Arteriosclerotic heart disease, including coronary disease—Males: Standardized mortality ratios, 1950–53.

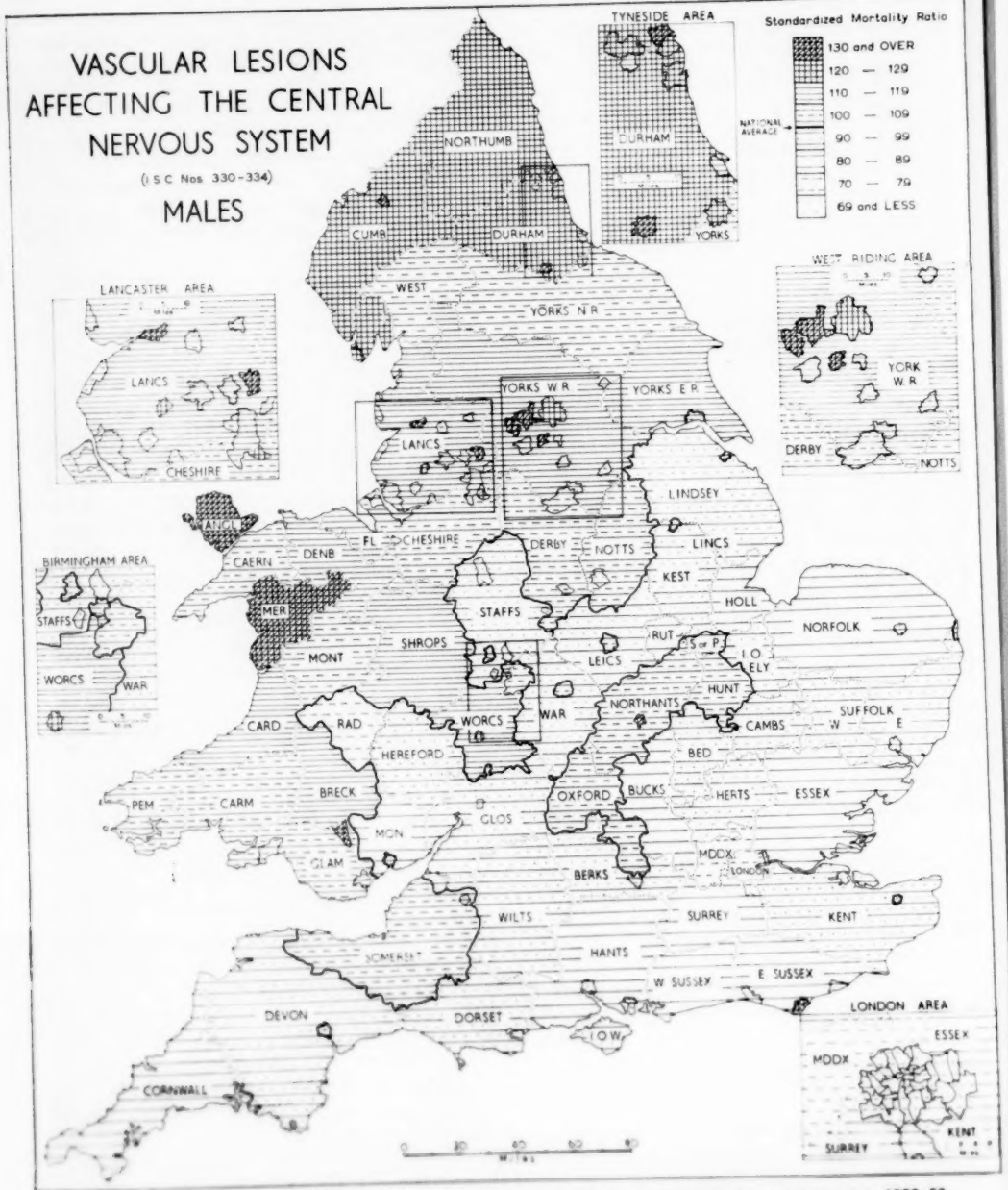


Fig. 2.—Vascular lesions affecting the central nervous system—Males: Standardized mortality ratios, 1950–53.

are above the national average and in some instances, e.g. Anglesey, Merioneth, and the county boroughs of Carlisle, Preston, Rochdale, Bradford, Halifax, Tynemouth and Darlington, the ratios are over 30 per cent above the average (Fig. 2). On the other hand, except for Somerset, Oxford, Northampton and Huntingdon, and the county boroughs of Eastbourne, Canterbury, Yarmouth and Exeter, the whole of the south-west, south and south-east of England has a favourable mortality experience from these causes. It seems unlikely that the tempo and tensions of our modern urban environments can be incriminated here, since mortality was lowest in Greater London.

3. Malignant Neoplasm (Cancer)

There are many different types of cancer. It is necessary, therefore, to distinguish between the different organs or sites that are affected, since the geographical distribution of incidence is different in each case, suggestive of differing causal factors. From the point of view of mortality two important sites are (*a*) the stomach, (*b*) the trachea, lung and bronchus.

(*a*) *Stomach.* There is once again a general tendency for the geographical pattern of mortality incidence to show high rates in Wales and the north-west of the country and low rates in the south and east (Fig. 3). There are, however, exceptions. The Fenland—Lincoln (Holland), Isle of Ely, Huntingdon—is a high mortality area. So is Northumberland and Durham and also the County of London (though not *all* the metropolitan boroughs—see inset map in Fig. 3). Cumberland, Westmorland and the North Riding of Yorkshire, it will be noted, contrast with the general trend of high incidence in the North of England by recording mortality ratios below the national average.

Caernarvon, Merioneth and Cardigan represent a contiguous area of high mortality rates, over 45 per cent above the national average throughout. One wonders what it is that is unique or exclusive to this geographic area to account for this unfavourable mortality experience from stomach cancer? It has been suggested that people eating vegetables grown on soils of high organic content—like peat soils—are deprived of protective substances because of micronutrient deficiencies in the soil.[6] The present writer would urge that increasing attention be devoted to the character of the rural water supply, to the untreated rural water supplies of this part of Wales,[7] and especially to those polluted with effluent from erstwhile lead mines, which are widespread in these counties.[8] When exposed to the atmosphere in spoil mounds the heavy ions of galena (the ore of lead) are oxidised and become soluble in water. Stream water thus becomes chemically polluted and toxic, as is evidenced by the frequent dead trout in certain of the streams in West and North Wales after heavy rain.

Even so, such factors would not explain the very high rates in Merthyr Tydfil (S.M.R. 166), Warrington (S.M.R. 161), Salford (S.M.R. 161) or Sunderland (S.M.R. 161). The obvious question, and a pointer to needed research is, 'What is there that is peculiar to these high mortality areas that is absent in the other more favourable areas?'

(*b*) *Trachea, Lung and Bronchus.* The pattern for cancer of this site is very different from that of cancer of the stomach. The high incidence in the urban areas, and especially in the conurbations, is now very obvious (Fig. 4). Whereas, for instance, Wales and more particularly the rural counties of Wales showed high rates for stomach cancer, the mortality from lung cancer in Wales is everywhere well below the national average, except for Swansea, Cardiff and Newport. Again, in the Lancashire–West Riding or in Northumberland–Durham areas, where stomach cancer rates were high, it is the conurbations and large towns now rather than the surrounding countryside which have the high mortality rates for lung–bronchus cancer. Essex, Hertford and Surrey stand out with an unfavourable mortality experience, but in this area London County (S.M.R. 156) and Middlesex (S.M.R. 121) have the highest rates. St. Pancras, Finsbury and Bethnal Green have mortality rates from lung–bronchus cancer which are over *twice* the national average, while Bermondsey, Islington, Shoreditch and Southwark are only very slightly better with rates over 75 per cent above the national average.

That there is a relationship between high mortality rates from lung cancer and densely populated areas is quite obvious. At the same time we know that where there are people there is atmospheric pollution—the larger the area of population, the larger the area of pollution. But such pollution as observed at ground level is a maze

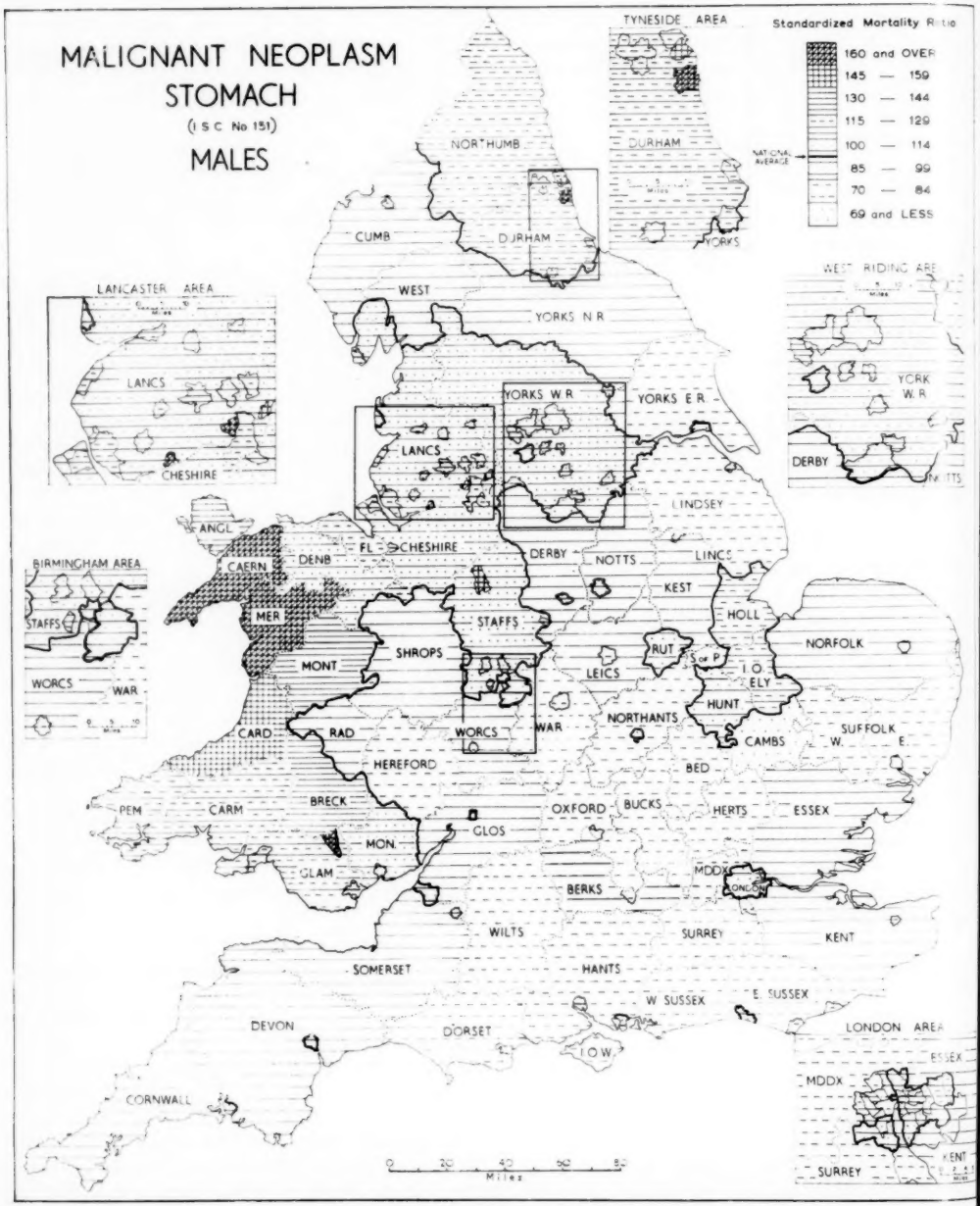


Fig. 3.—Malignant neoplasm, stomach—Males: Standardized mortality ratios, 1950–53.

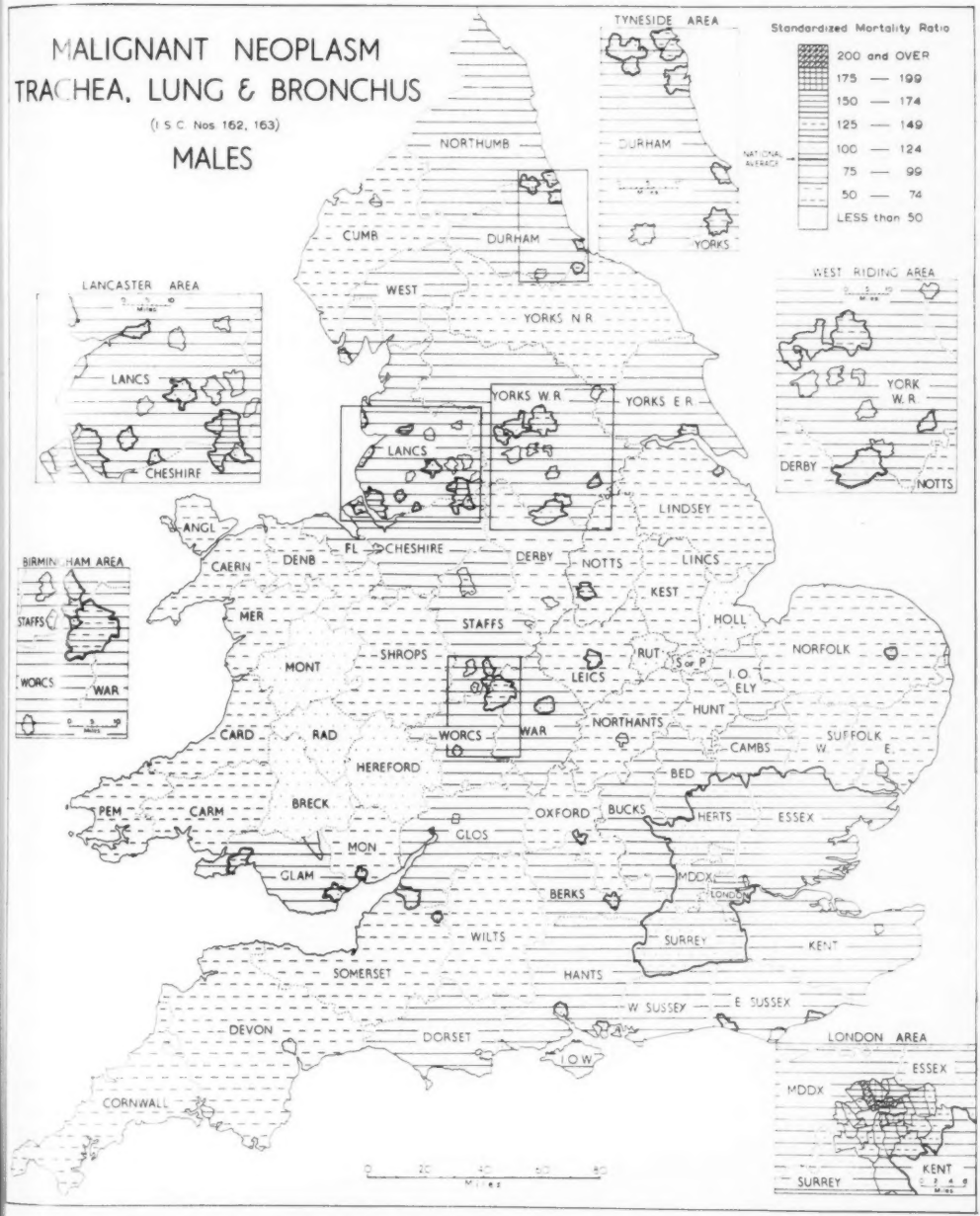


Fig. 4.—Malignant neoplasm, trachea, lung and bronchus—Males: Standardized mortality ratios, 1950–53.

of considerable complexity, for it includes not only general pollution with smoke (about 80 per cent of which is due to domestic coal-burning fires)[9] and sulphur dioxide, but carbon monoxide from road vehicles and specific industrial hazards like silica dust, asbestos dust, or respiratory carcinogens from such metals as chromium, nickel and arsenic and their compounds. Furthermore, atmospheric pollution at higher levels cuts off light, solar radiation and the important ultra-violet radiation which can lead to a general lowering of the level or standard of good health. Until a final and definite evaluation of the significance of the various components of atmospheric pollution is made, the only effective control of these diseases (apart from the additional hazards of cigarette smoking) would seem to be the reduction and ultimate abolition of atmospheric pollution. The new Clean Air Act, therefore, gives rise to optimism in this direction.

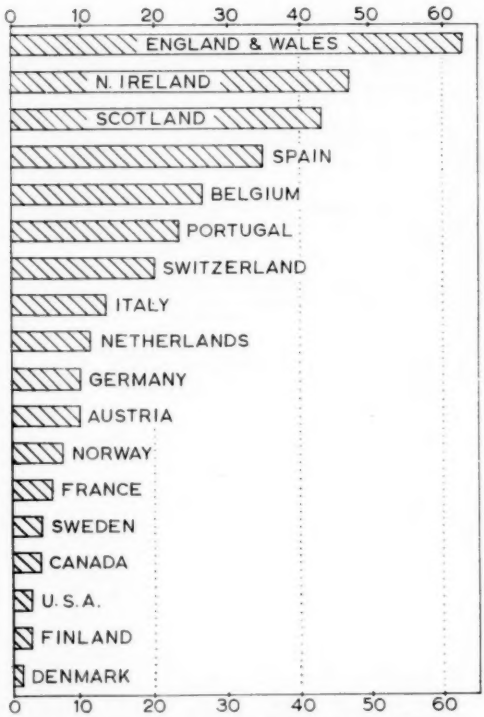


Fig. 5.—Bronchitis death rates per 100,000 in 1950.

4. Bronchitis

Bronchitis is often called the 'English disease' because of its particularly high incidence in this country (Fig. 5). The outstanding feature of the distribution map (Fig. 6), as with the lung-bronchus cancer group of diseases, is the marked correlation between areas of high incidence and areas of dense and especially industrial populations as in South Wales, the London area, the Midlands, Lancashire, West Riding of Yorkshire and Nottinghamshire. However, in contrast with the lung-bronchus cancers, which are noticeably concentrated in the county boroughs of industrial areas, high rates for bronchitis mortality would seem to be rather more widespread within the industrial areas.

6. All Causes

The quite remarkable regional variation in the geographical incidence of disease mortality in England and Wales has been demonstrated in Figs. 1–4 and 6. Seemingly, what one region gains on the 'health roundabout' it loses on the 'disease swings'. But what of the synthesis, the distribution for 'all causes' of death taken together? Have some areas a more favourable mortality experience than others? Looked at from the point of view of those fortunate enough to have any choice in the matter, it is the question of 'where to live'.

The group of counties and county boroughs with very high overall death rates (18–27 per cent above the national average) and those with the very low overall death rates (7–15 per cent below the national average), for either males or females or both, are shown in Fig. 7. Those with the highest rates are all within the Highland Zone and those with the lowest rates are all within the Lowland Zone. The actual areas with the most unfavourable mortality experience are Glamorgan, Carmarthen, Cardigan, Merioneth, the urban areas of Anglesey, Pembrokeshire, Cumberland and Rutland and the rural areas of Montgomery and Caernarvon, Flint and Durham. It is significant that of these, only three—Cumberland, Durham and Rutland—are not situated in Wales. Nine out of the ten county boroughs with the highest S.M.R.s were in the north of England and seven of these—Salford, Liverpool, Manchester, Wigan, Oldham, Rochdale and Burnley—are in Lancashire. The other two

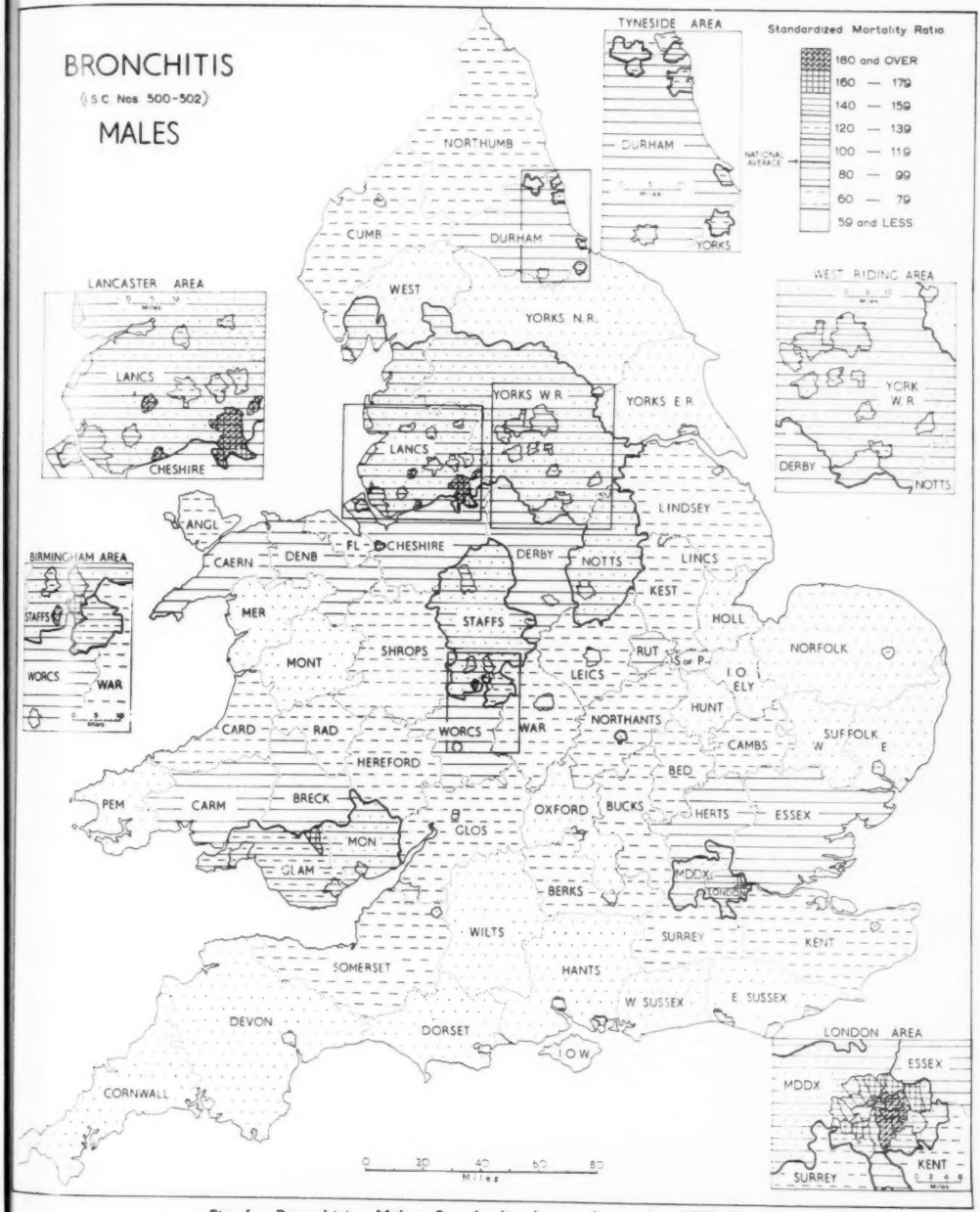


Fig. 6.—Bronchitis—Males: Standardized mortality ratios, 1950–53.

are Dewsbury and Middlesbrough. The tenth is Merthyr Tydfil in Glamorgan.

The best areas for males or females, or both, are in East Anglia and the south of England—Surrey, Sussex, Buckingham, Middlesex, urban Cambridgeshire and Hertford and the rural areas of Wiltshire, Oxford, Soke of Peterborough, East Suffolk, Norfolk and the Isle of Ely. Of the best county boroughs, ten are situated in the south or south-east of England. They are Bath, Reading, Canterbury, Croydon, Eastbourne, Ipswich, East Ham, Southend-on-Sea, Oxford and Bournemouth. Only Smethwick in Staffordshire is out of the general southern and eastern area of the country, and its advantage is for females only (S.M.R. 93).

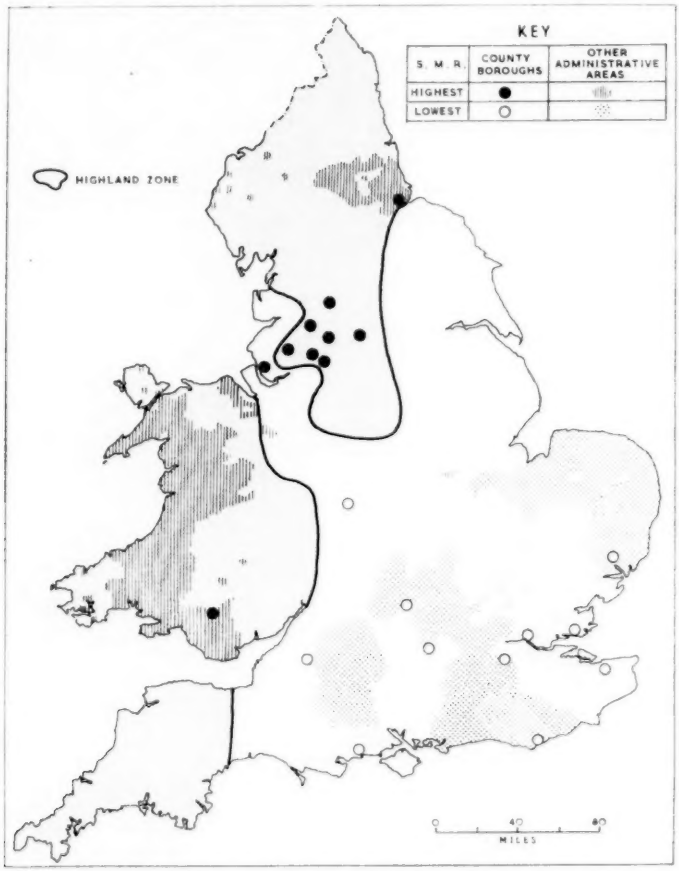


Fig. 7.—Areas with highest and lowest standardized mortality ratios for 'All Causes'—males and females, 1950–53.

Of the six major conurbations, only Greater London had an S.M.R. below the national average —7 per cent below for females and 3 per cent below for males. Each of the five others—south-east Lancashire, Merseyside, Tyneside, West Yorkshire, West Midland—had S.M.R.s above the national average, with the Merseyside conurbation the greatest excess for males (S.M.R. 116) and

south-east Lancashire for females (S.M.R. 112). The favourable position of Greater London should not detract, however, from the notably high S.M.R.s of certain metropolitan boroughs. Southwark has an S.M.R. of 124 for males and 107 for females, Stepney 123 and 111 respectively, and Shoreditch 118 and 111 respectively.

At the mid-twentieth century the average risk of dying in the worst of the Highland Zone counties and county boroughs was between 30 and 40 per cent greater than in the best of those in the Lowland Zone. The Highland Zone shows mortality rates, from all causes combined, 10 to 11 per cent above the national average, whereas parts of the Lowland Zone have rates 7 to 11 per cent below.[10]

While the unfavourable mortality experience of the Highland Zone does not apply to all diseases individually, one cannot but speculate as to which aspect of the physical or human environment of the Highland Zone is favourable to so many disease viruses or bacteria, or to their intermediate hosts, and yet is not present in the Lowland Zone. The question also arises as to whether there is any hereditary or genetic weakness or liability to disease on the part of some people, say, the Celtic people found throughout the Highland Zone, compared with the possible hereditary or genetic resistance on the part of those of Anglo-Saxon stock of the Lowland Zone. Of course, the unfavourable mortality experience of the Highland Zone may also reflect the malnutrition of the 'Hungry thirties' and/or overcrowding in oftentimes insanitary habitations, either in the rural areas or in the 'traditional' heavy industrial regions.

CONCLUSIONS

One cannot be dogmatic about any apparent spatial relationship between the distribution of disease and the manifold features, physical and human, which diversify the landscape of England and Wales. Marked regional variations in the incidence of individual diseases certainly exist, and one might be tempted to instance what appear, at first sight, to be direct or indirect causal relationships with some factors of the environment or with certain people. There may be a correlation between disease and some aspects of climate, possibly operating through food and water supply, atmospheric pollution, soil type, sanitary and social environments and upon micro-organisms and their insect and other vectors. A possible hereditary predisposition to a particular disease on the part of some people may be indicated by a parallelism between its geographical distribution and that of a specific human blood group. Again, a particular disease at the present time may reflect the increasing sedentary nature of work in the twentieth century, our diet, or the tempo, tensions and anxieties of our daily life.

The answer probably rests with a whole complex of causes which can only be resolved by team work between workers in medicine and allied sciences, together with geographers. I am convinced that the areal viewpoint of the geographer, his examination of space relationships and his experience in integrating the varied and numerous aspects of the total environment, offers a valuable complementary approach to the solution of many medical problems.

REFERENCES

1. CLARK-KENNEDY, A. E. (1957): *Human Disease*, p. 7. Harmondsworth, England.
2. HIRSCH, AUGUST (1883–6): *Handbook of Geographical and Historical Pathology*, 3 vols. (New Sydenham Society, Vols. 106, 112, 117). London.
3. General Register Office (1951): Census 1951, England and Wales: Preliminary Report. H.M.S.O., London.
4. The Registrar-General (1958): Decennial Supplement, England and Wales, 1951: Area Mortality. H.M.S.O., London.
5. MORRIS, J. N., 1957, *Uses of Epidemiology*, E. & S. Livingstone, Edinburgh and London. See also Morris, J. N., Heady, J. A., *et al.*, 'Coronary heart disease and physical activity of work' *Lancet*, 265, pp. 1053 and 1111 (1953).
6. LEGON, C. D. (1951): 'A note on geographical variations in cancer mortality with special reference to gastric cancer in Wales', *Brit. J. Cancer*, **5**, 175.
7. HOWE, G. MELVYN (1959): 'The geographical distribution of disease, with special reference to cancer of the lung and stomach in Wales', *Brit. J. prev. soc. Med.* **13**, No. 4.
8. —— (1960): 'The geographical distribution of cancer mortality in Wales, 1947–53', *Trans. Inst. Brit. Geogr.* No. 27 (in the press).
9. Personal communication from F. P. Williams of Warren Spring Laboratory, D.S.I.R., dated September 26, 1960. 'The yearly average smoke pollution will lie somewhere between 100 and 300 μg./cu. m. in any town with a population of 5000 or over, except perhaps . . .; small villages or any collection of domestic dwellings will be liable to a very localised smoke pollution in excess of 100 μg./cu. m., at least during the winter.'
10. The Registrar-General (1958): *op. cit.*, p. xiii.

VERNACULAR PLANT NAMES AND THEIR BACKGROUND IN NORWAY*

By Prof. Dr. OVE ARBO HØEG *Department of Botany, The University, Oslo*

If you walk up to a Norwegian farm with your thick notebook and pencil in hand, and tell the farmer that you would like to write down all he knows about local plant names and uses of wild plants, then I do not think that you would actually be kicked out of the farm, but you would certainly have no chance of establishing cordial relations with him, and your notebook would not become any fatter. On the other hand: if you walk up to him slowly, say 'Good Afternoon' and talk about sensible matters like the weather, and the crops (if you can do so without exposing gross ignorance in agricultural matters), and after some time casually bring in a question about some common plant you may have brought with you, and about which you are confident that he knows at least the name, then you are on the right track. You may end up by sitting with him for hours on a grassy slope, and he may end up by thanking you, not so much for what you have told him during your interview, but for the interest you have shown in what he has been able to tell you and which now fills page after page in your notebook. If you get the opportunity to come back on the next day, then you may get a rich after-harvest of half-forgotten reminiscences which have come up from the subconscious during the night. It would be best of all if you could live with him on his farm, be with him in his work in fields and meadows, in forest, bogs and mountains, talk with his wife, spend hours with the old grandmother and grandfather in the house, and, not least, watch the children play, then you would again and again find something to put down in your notebook. Most probably you would be amazed to discover how much there still exists of old local tradition of plant names and about how wild plants were used; what people said and thought about them.

Up to fairly recently, only a few generations back, the life and economy of the majority of Norwegians were based on local production. People did not buy much; money was not much in circulation outside the towns. They lived on what the soil and sea produced. Life was not easy, and they had to use everything that could possibly help them in the struggle for existence. From time immemorial oral tradition carried down knowledge about the properties of plants and what they could be used for, and this practical, rational experience often became mixed up with, or changed by, superstition of some kind or other.

It has been like that in all countries—very much so in Britain, where agriculture through all ages has meant so much for the cultural development and the economy of the country, and where rural life went on along the traditional lines for century after century.

But in Norway the population has always been much smaller in relation to the area, there is more variation in the country within fairly short distances, from the beach up through valleys, forests, bogs and lakes to the mountains. People lived closer to this nature which we often, erroneously, think of as untouched. They were poor, but they were free (the freedom of the Norwegian peasants in contrast to the contemporary conditions on the Continent is remarkable and important also in this connection). People were never taught botany, but they knew quite a lot about plants.

Let us take some examples. A farmer knows, or at least has an opinion about, what *kind of wood* is best for a particular purpose—for various parts of wagons, sledges, boats, houses, implements, big

* Paper given to Section K (Botany) at the Cardiff Meeting of the British Association, September, 1960.

and small. The opinion *may* vary from one district to another, but at all events, it is there, and it is based on an intimate knowledge of the wood of the different trees. For instance: the houses in the rural districts, and in towns, too, used to be log houses, built from straight stems of Scots pine placed horizontally and fitted into each other in the corners by means of corresponding notches. The stems, resting on top of each other, were trimmed by means of the axe so as to leave as small opening as possible, and between them moss was used for packing. In Eastern Norway they mostly used *Sphagnum*, but if you said that to a man from Western Norway he would have difficulties in concealing his contempt, because in his opinion only *Hylocomium* serves the purpose. Now the trunks of pine (and spruce as well) practically always have a spiral arrangement of the elements of the wood, and as a rule the growth is anti-clockwise, against the sun, while there are exceptions twisting the other way. This fact influences the way in which the wood moves, or 'works' as we say, with changing humidity. In a wall where all trunks are twisted the same way they will keep each other in check, while if there is a single trunk of the unusual type, it will move in relation to its neighbours in such a way that the moss packing falls out, and one will get an open crack in the wall, and draught and rheumatism. This was not known by everybody, but the best carpenters, and farmers, knew it and avoided the wrong kind of trunk.

Even in connection with the uses of wood superstition still exists. The wood of *Sorbus aucuparia* (rowan or mountain ash), which is common all over Norway, should not be used for anything in a boat. An exception (which was rarely met with) was that it might be used in the keel, because it was said to keep the boat down and make it steady, but the general rule was that rowan should not be used at all for any part of the boat, and it should not even be brought on board. If people had taken wood with them, for fuel, and they found that there was a piece of rowan wood, it would be thrown overboard. It is true that rowan was not always said to bring bad luck with it. In the south-eastern corner of Norway it was a custom not very long ago, although possibly forgotten now, that if a baby was sleeping outside the house one should place some branches of rowan around its cot. That would keep bad spirits away. The connection between rowan and supernatural forces has very long roots in Norway. That is evident from the old Norse mythology, from an amusing story about no less person than Thor himself.

Rowan, and elm too, must not be used for skis. In the case of elm the explanation is frequently given that elm was so valuable for making bark bread that one should save it for that purpose. I dare not express any opinion about that point. In the case of rowan, however, I am sure that the magical element was the main thing.

Also in connection with *Alnus*, alder, there has been some superstition (which is still remembered). Boys herding cattle must not beat the cows with twigs of alder. If they did, there would be blood in the milk. The most probable explanation is that the red colour of the bark and wood of alder has given rise to this belief.

About juniper there was perhaps more superstition than about any other woody plant in Norway, and in addition it was used very extensively for practical purposes. However, the examples I have given will have to suffice to show that the use and the avoidance of different kinds of wood was based on practical experience and intimate knowledge of the properties of wood, but might also have a strong sprinkling of magic.

In the kitchen, people used *Equisetum hiemale* for scrubbing their wooden vessels, in which they kept milk. These hard stems, with a high silica content, are excellent for that purpose. It was commonly said that some persons have a special gift for finding the plant, which is not always so easy to see. It was used in the same way here in Britain, as witnessed by its name scouring rush.

Small bundles of *Lycopodium annotinum*, a kind of club moss, were also used in the kitchen, for scrubbing pans and kettles. In certain parts of the country this practice has been kept up till quite recently. In fact, I know it happened during the last war, such bundles being for sale in small country shops. It must be *annotinum* and not the other species, *clavatum*, which is softer and less solid. Although I knew this I once asked a farmer if he could not use *clavatum* as well as *annotinum*. He looked at me with a slightly hidden feeling of superiority and said: 'Yes, but only as a toy for children.' A farmer could recognise and distinguish between these two species at many metres' distance out in the forest.

The common rush, *Juncus effusus* and *J. conglomeratus*, was used in Norway in a way not very much different from the old English custom mentioned by Shakespeare and others. One took the white internal aerenchyma of the stems. In England that was used for rush candles—which did not give very much light, to judge from Mr. Pickwick's description of a solitary candle of that kind in a large, dark room. In Norway I have never come across exactly that use, but it served as a wick in the oil lamps which were fairly common in the old days. Some of the still existing names for this rush refer to that usage.

Quite commonly ropes were made from the cortical fibres of the lime tree (*Tilia*). They were of an excellent quality.

People used to keep as large a stock of cattle as possible on the farm. Towards the end of the winter there was always a terrible shortage of fodder, and it was important to let the cattle out as early as there was the slightest chance to find anything at all to graze on. Later in the summer the cattle, in many parts of the country, were brought up to out-farms in the mountains close to the timber line, corresponding to the Swiss 'Sennhütten'. Here they spent the summer months together with a couple of women who looked after them, milked them, and made butter and cheese.

All this gave the people a very intimate knowledge of the best plants for grazing. Among them *Deschampsia flexuosa*, the 'wavy hairgrass', ranked highest, with its delicate leaves remaining soft and juicy during the whole summer, in contrast to, for instance, *Nardus*, the 'mat-grass', which becomes very coarse and stiff.

Another plant with a very good reputation, at least in western Norway, is *Salix herbacea*. I suppose that very few who have seen this tiny alpine willow, creeping on the ground, and with leaves at most half an inch across, would think it of any value at all. However, the sheep are of a different opinion, and there is a small verse, of two lines, in which a sheep says that if she were sure to find this plant she would be willing to walk a mile (and that is a Norwegian mile, which is six of the English miles).

Early in the summer people started to think of the supply of fodder for the long winter, when the cattle had to be kept indoors. Artificial meadows, with clover, timothy, and other cultivated plants, have been used in Norway for less than 100 years. Before that people used to cut grass where ever they could do so, dry it, and either bring it home at once or stack it and transport it home in winter, on sledges. To a great extent this hay consisted of *Eriophorum*, *Carex*, *Scirpus*, and other monocotyledonous plants growing on bogs. Most of these hay plants were lumped together under the common name of grass, if growing on fairly dry ground, while the bog plants mostly were called '*storr*', which is the Norwegian equivalent of your sedge. People had a specific name only for a few plants of more particular value (as in the case of *Deschampsia flexuosa*).

I would like to say a few words here on what might be called popular nomenclature.

People always give a common name to a group of plants which, for practical purposes, have identical properties. It is probably like this in all languages—in English you have grass, sedge, rush, and corresponding concepts and words occur in Norwegian. On the other hand it happens that there are more minute distinctions than used by the botanists. I have mentioned that *Deschampsia flexuosa* is regarded as the best grass for grazing. Therefore it has a specific vernacular name, but this only applies to the leaves. The popular name, which is '*smyle*', does not include the culm. If you need to speak about that part of *Deschampsia flexuosa* at all, then you must use a word which this species has in common with some other fairly tall grasses with more or less similar inflorescences, because to the farmer and his wife and his cattle, the culms were of no great interest. A botanist would use a different classification of course, and apply the word *smyle* to the complete plant of *D. flexuosa*.

Similarly we have the case of *Eriophorum vaginatum*, the 'cotton grass' which is common on bogs all over the country. The flowering stems appear as black heads on the surface of the bog very early in spring. That is regarded as a sign that the cattle will be able to find something to feed on, both because the young tender stems of *Eriophorum* are eagerly eaten by the cows, and because experience shows that when these black heads appear, then other plants have developed far enough to be of at least a very modest value for grazing. Therefore people have local names for these black heads in early spring. Later in the

summer the same *Eriophorum* plants produce their well-known white cotton heads which we call bog-wool. No sensible person would think of using the same word for the plant in spring and in summer!

There are plenty of corresponding cases in the animal kingdom, probably in most languages. Zoologically a horse may be the same species whether young or old, but who would call a new-born foal a horse. On a Spitsbergen expedition I once heard a discussion between a geologist and one of the men, who was from northernmost Norway and used to seal hunting. For one and the same species of seal he had different names for the animal of different ages—for the new-born ones, the one-year-old, and so on, and no name common to the whole zoological species. He and the scientist did not understand each other. They simply did not speak the same language. Try and ask a farmer if a calf is the same as a cow!

To return to the winter fodder. There was practically never enough hay, and people used all kinds of additional fodder.

What they called 'moss' was important in many districts. It was, of course, lichens, which were gathered in the mountains and brought home on sledges in winter—a good fodder, although poor in proteins.

More widespread and important than the use of lichens for winter fodder was the use of twigs and leaves of trees. Elm was regarded as the best, but the twigs mostly used were those of birch. They were cut in summer, about 2 ft. long, and tied up in bundles, placed for drying, and stored for the winter. In this work a man and a woman mostly worked together, and if it was paid work, or duty, then there was an agreement that they should make a certain number of bundles per day. If they made more they would get additional pay. These bundles were counted in hundreds, and an interesting thing is that a hundred did not then mean 10×10, but 120, which is the old 'big hundred'. This is a survival from very old days. In a few other connections the big hundred has been used right up to our days, but now most people have forgotten it. As a subsidiary fodder, bark shavings were also used.

Among the many other kinds of fodder I may only mention the rhizomes of certain plants. Of course, weeds were extremely plentiful in the fields. People did not do very much to get rid of them, but perhaps they did what they could. For instance in the case of dock (*Rumex domesticus*), they used to pull it up some time about mid-summer. In certain parts of the country they said that there was one particular week when it was possible to get it up with the complete root. There are also places where it was said that the root would loosen most readily from the soil when the moon was waxing or (in other places) when the tide was coming in (one should have expected waning moon or outgoing tide, but that was not so in the few cases I have come across). In one place, when I was sitting with a young farmer and his brother, who was a teacher, talking about these things for several hours, I asked them whether anything was said in their district about the influence of the moon or the tide on the dock root. With some contempt the teacher said: 'There is so much superstition about the moon, but that it is easier to get the dock up with the root when the tide is coming in, is certain enough. That I have noticed myself.'

The dock root was scarcely used for fodder, chiefly because it was pulled up at a time of the year when grazing was plentiful. But the rhizomes of couch-grass (twitch), *Agropyrum repens*, were often carefully gathered together during harrowing in spring, brought to a stream to wash the sand off, and given to the horses for food. Also the roots of *Ranunculus repens*, the creeping buttercup, were used. Both of them are certainly of considerable nutritive value. The thick rhizomes of the big ferns, *Dryopteris filix-mas*, the 'male fern', and others, are full of starch and were used in the northern half of the country for fodder. People said that *Athyrium filix-femina*, the 'lady fern', was poisonous, and they were able to recognise its rhizome without leaves because the remaining basal portion of the petioles have nodules along the sides, which you can feel with your fingers. They do not occur in other ferns. It is rather surprising that such a small detail has been discovered.

That the cattle suffered from scarcity of food during winter was a regular feature. However, not only the cattle would suffer. If not in ordinary years, then certainly in years when crops failed, as often happened, people faced grave difficulties. Then old experience about eatable wild plants would be remembered and become useful. Only a few examples may be mentioned. That people made bark bread in 1812 has lived in tradition right up

to our days. However, it was not only in 1812 that this happened, but in other years of failing crops as well. The bark of Scots pine was most commonly used, but the bark of other species was also employed. The inner portion of the cortex contains starch and protein and is certainly not without nutritive value, even if the resins of the pine might be harmful. Elm bark was regarded as by far the best, certainly with good reason. Therefore the elm trees were valued more highly than other trees. I have met a man from one of the West-Norwegian fjord districts, who told me that when he was a boy they used to make flour from elm bark, and that this activity was a regular task in the home. They removed the outer part of the cortex, with the cork, and then shaved off the white inner bark, dried it carefully, ground it, and mixed it with other flour. Elm bark is not only nourishing, but is also a good admixture to bad flour made from cereals not properly ripened, because it will keep the dough together, whether it is used for leavened or unleavened bread. Perhaps the commonest type of bread in Norway used to be an unleavened one, flat, thin, rather like paper. A housewife took pride in making it very thin. That was particularly difficult with flour of poor quality. Sometimes some pieces of elm twigs were left in a cup of water overnight. A mucilage from the twigs would then make the water viscid, and this was used as liquid for making the dough.

Evidently, lichens have never been used much for human food in Norway, only *Cetraria islandica* to a small extent, and *Umbilicaria* still less. Fungi were detested by the population. Red seaweeds, which were in common use since the times of the sagas in Iceland, have probably been eaten in Norway as well, but there is no direct evidence of it. Even so, the people of the coast had a knowledge of quite a number of species of algae, and had names for them.

Underground parts of plants have been eaten. They would not supply any great quantity of food, but might be a welcome addition. Only a few examples will be given.

Potentilla anserina, the 'silverweed', has storage roots about 3 in. long and the thickness of a pencil, full of starch. They were called 'mura' in Old Norse and were mentioned in the sagas. In Iceland tradition about them survived in fairy-tales but also in practical usage. We do not know when they were last eaten in Norway by adults seriously needing food. Nowadays one may only come across very rare cases of children gathering them in spring-time and eating them after cooking. *Conopodium majus*, the 'earth nut', is common along our west coast. There children like to dig up the round tubers and eat them because of their good taste. There is no evidence that they have ever been of any importance as food, but we have at least a linguistic proof that they have been known for more than 1000 years, since the Viking Age: in Normandy this plant is called '*jarnotte*', and similar names are known in Yorkshire: *yernut*. It is impossible to doubt that this is derived from the old Norwegian name '*jornot*', as the plant is still called, and which means 'earth nut'. It does not grow in Denmark, so the name must have come from Norway.

Children have also kept up the practice of eating other plant organs, which formerly *may* have been of practical use to grown-ups. The children now eat them in spring-time, because they like the taste and probably also on account of an unconscious demand for vitamins.

Among the underground organs, beside those mentioned, are the tubers on the rhizomes of the common horsetail, *Equisetum arvense*, and those of *Lathyrus tuberosus*, and among the green things the leaves and young shoots of a remarkable variety of plants. Among the most interesting ones are the young fronds of the fern *Botrychium lunaria*, the 'moon-wort'.

Among the green herbs eaten in spring or early summer none was more popular than *Archangelica officinalis*. It is common in the mountains all over Norway, mostly growing in large groups in moist places. The plant grows for a couple of years without flowering, forming its very large leaves only, and then it produces a flowering stem, sometimes higher than a man, and dies. People know the plant very well. In the north they have one name for the plant in the vegetative state and one for the flowering stem. The tender young petioles and stems have a strong, highly aromatic taste and have been regarded as a delicacy, eaten raw. Young people used to make excursions in June in order to gather and eat '*kvanne*': boys gave their sweethearts selected stalks as a gift, and sometimes enterprising boys had them for sale when people met at the church on Sundays. The plant has

long history behind it in Norway. In one of the sagas it is told that in the year A.D. 1000 the king crossed the market place in the town of Trondheim and noticed a man who had for sale some kvanne, which was unusually big for that time of the year. He brought some back to his queen. However, she did not appreciate it and instead reproached him for not having fetched some property she was entitled to from Denmark. Result: War. The king fell and the history of Norway changed its course.

The plant was transplanted from the mountains into primitive gardens in the mediaeval ages in Norway. That is even mentioned in the old laws. Remnants of such gardens have existed in a few places in western Norway up to our days.

Berries and hazel nuts were of course popular among the children in the autumn, but it is a surprising fact that the peasants cared very little for such berries as blueberry and red whortleberry, which abound everywhere. They *might* pick and eat some in the autumn, but they did not make jam or any other kind of preserves, probably, at least partly, because sugar was a costly luxury. In certain parts of the country they might store red whortleberries in plain water and eat them in the course of the winter without adding any sugar at all. Cloudberries, *Rubus chamaemorus*, have always held a position of their own and still do. In certain years it is extremely plentiful on the bogs, particularly at some height and in the north. The berries keep well, if simply stored raw in barrels (or as the Lapps did it, in reindeer stomachs), and they have formed an important vitamin source, particularly in the northern part of the country.

Before leaving such eatables I may mention that caraway seeds have been a very popular spice all over the country, and the herb *Origanum vulgare*, 'wild majoram', was also used rather extensively and until recently sold in small bundles in some market places.

For their beer people used to grow some hops, but certain other plants were evidently more used, particularly juniper, also some *Myrica gale*, 'bog myrtle'.

The use of plants for medicinal purposes is a very long story. There are two main aspects of it. One is the practical, rational experience without any fuss or secrecy about it. Just as people knew that some plants are good for eating, so also they knew that some plants have a good effect on wounds or in cases of diseases. The other is of a magical nature, based on the belief that behind everything that happens there is an invisible force, and if you can influence that force you are able to change the course of events. These two trends intermingle, and the more there is of the magic, the more the secrecy.

The school medicine of the learned people, from classical times and up to quite recently, has influenced the folk medicine, not always for the good. Folk medicine has faithfully preserved many of the theories and practices of the learned doctors, long after *they* gave them up and started to treat them with contempt. This is particularly noticeable in the case of the doctrine of signatures. It is an old belief that plants, and other objects in nature, by shape, colour, or other properties, show what kind of disease they are effective against. This idea was made into a quasi-scientific system by Paracelsus about the year 1500. In folk medicine we now meet this idea very frequently. The lichen *Xanthoria parietina* and other yellow plants, and the bird known as the yellow hammer, too, have been used against jaundice: plants with heart-shaped leaves against heart-diseases, and so on.

Linnaea borealis has been widely used in Norway against herpes zoster, shingles, certainly because its long creeping stems grow out in a way recalling the spreading of the disease on the body. *Veronica officinalis* and *Antennaria dioica* were used in the same way, no doubt for the same reason.

Potentilla erecta, the 'tormentill', common all over Norway, gives a good illustration of several sides of folk medicine. The rhizome contains tannin, which gives a rational explanation of the good effect with which it has been used in Norwegian folk medicine against diarrhoea, and on wounds to stop bleeding, and against stomatite. The rhizome is red inside. That explains why it has been used against various other diseases where it had probably no physiological effect (but possibly a psychological one). Finally, the flowers have a fine yellow colour and four petals arranged in a cross. They have not, to my knowledge, been used for medicine, but it was supposed that they had a good effect on milk: in certain places on the west coast it was a custom to place one of these flowers in the bottom of the bucket the first time the cows were milked out-of-doors in the spring, no doubt because the rich yellow colour and the shape of

the cross were supposed to bring luck. A man told me once that when he was a boy it was of course strictly forbidden to throw anything into the milk, but there was no objection to a flower of *Potentilla erecta*.

Plants were very commonly used as calendars. It is all very well to know what day of the month it is, or that it is this or that Saint's day, but it is much more useful to know how far the seasonal development of the vegetation has advanced. In large parts of the country it was said that when *Anemone nemorosa* is in flower, then the sheep, or sometimes other domestic animals, will be able to find their own food. The primrose holds a similar position, particularly with regard to cows, and both of them have corresponding names. When the young leaves developing from the buds of birch, or alder, were as big as mouse ears, then it was time for various undertakings related to agricultural matters, fishing in freshwater, and so on. Most of the calendar signs referred to the development of spring, but there were others showing when one should start hay-making, harvesting of cereals, and so forth.

Finally: the children. They have their own way of looking at plants, and they have had innumerable ways of using flowers, straws, leaves, cones, and other plant organs for play and games, which have given rise to still more plant names. Conservative as children are, they have handed down from one children's generation to the next an abundance of experiences and customs, some of which date very far back. For instance: *Plantago lanceolata*, the 'ribwort', which is common in many parts of Norway, has been used for a kind of game along the west coast and parts of the south coast. On Midsummer night one should take a flowering stem, pick all the stamens off the flower head, and place it under the pillow, or place two of them in a cross on the window sill. If then, in the course of the night, new stamens had developed, it was a good omen. One should either live at least till the next Midsummer, or have luck in love or other important matters, varying from one district to another. I once made some experiments and found that in about fifty per cent of the cases new stamens would really develop, because only some of the flowers of the inflorescence open every day, and it takes only a few morning hours for stamens to straighten out and attain their full length. Now, where this game was played (and only there), the plant was often called by a Norwegian word which would correspond to 'St. John's wort'. It is rather remarkable that also in the Faeroes and Shetland the plant has names referring to St. John. In Shetland the commonest name was John's Mass Girs, and there the plant was used for the same kind of play. It is scarcely possible to explain this fact in any other way than as a remnant from the time before the connections between Norway and the islands to the north of Scotland were severed, that is, before the 1460s.

I have only been able to touch the fringes of a vast subject but I hope I have demonstrated that the common people of Norway knew quite a lot about wild plants. In any particular district some knew more than others, perhaps because of greater intelligence or greater interest, or because of more opportunity of hearing folklore from older people, or because of differences in their daily tasks—the farmer had one field of interest, his wife another: some people were skilled in wool dyeing; a few others became known as skilled doctors for people and for domestic animals. Taken all in all the sum of such diverse knowledge was quite considerable and in Norway, as in all other countries, names were given to the plants which were of importance in the life of the people. It is probable that the numbers of these names and of their dialect forms are greater in Norway than in many other countries; the names themselves have been little influenced from literary sources.

During the past thirty years I have collected some two hundred thousand notes on plant names in different parts of Norway and about the same amount of material about the uses of these plants and other botanical folklore. Also in the last forty years or so, other Norwegian botanists have been active in Norwegian ethnobotany. Rolf Nordhagen has published thorough and interesting monographs, and Jens Holmboe, Knut Faegri and others have also contributed to the literature on these subjects.

BRITISH ASSOCIATION NEWS

A NEW LOOK AT THE ANNUAL MEETING

By T. Brueton

I attended the Cardiff Meeting as a Science sixth-former about to start my final year in a local High School. The Association had become known to me through press reports of previous Meetings and, by a casual reading, I gained a vague impression of middle-aged, long-haired scientists delivering the fruits of their research to tense lecture-rooms, packed with middle-aged, long-haired scientists. At the first lecture I attended I realised that this impression had been false. The lectures proved to be pleasantly relaxed and intimate, while the many familiar faces in the audience made one feel quite at home. Many members confined their activities to one or two Sections, but although my primary interests are Mathematics and Physics, most of the lectures I attended were in other Sections. The content of the papers varied from the highly comprehensible to the rather esoteric: notes in the programme did not always indicate how much specialist knowledge would be assumed by the speaker. Another difficulty was selection—as there were usually three or four interesting lectures being given at the same time. Fortunately, the extensive press coverage helped to overcome the physical limitations imposed on one by space-time.

Images which I recall vividly from the programme of films (which included many of interest not only for their content, but also as works of art) are the strangely powerful paintings by schizophrenic patients and the sublime futility of a machine making pretzels with 'hand-tied' knots. It would have been useful if the films could have been repeated in the evenings, for they clashed inconveniently with the lectures.

I myself played a part in the programme of the Meeting by demonstrating some of the exhibits in the Science in Schools exhibition. The eagerness of the 'innumerate' visitors to understand the mysteries of Physics was most encouraging, and explaining the demonstrations gave unexpected enjoyment. I suspect that many of the visitors were science teachers spying out new ideas, for several made notes surreptitiously. The experimental section, with its wealth of fascinating apparatus, might possibly have given a distorted idea of conditions in school science laboratories. I felt, too, that if the exhibits could have been co-ordinated in some way, for instance by being arranged in a thematic sequence, the exhibition would have been more intelligible to the layman. It was, nevertheless, one of the liveliest I have seen, and proved interesting from 'both sides of the counter': one had an opportunity to see what one's contemporaries are up to.

The Association's awareness of the responsibility of the scientist was revealed in the Food and Population Symposium, which I found particularly stimulating, since many of the problems encountered had been discussed earlier at local sixth-form conferences. Questions which had formed in one's mind were cleared up by authoritative speakers, while at the same time new ones took their place. The general atmosphere seemed surprisingly optimistic in view of the facts: perhaps this was because of a wish not to discourage younger members of the audience. I feel that scientists should be more militant in putting forward their views on subjects like these, which are of vital importance. If there were a hundred such symposia throughout the country, the general public might begin to grasp the urgency of the problems involved and realise that this is not merely academic scientific discussion.

In retrospect, it is clear that an Association which can hold a social occasion in the middle of

the Summer Vacation, as successful as was the Students' Dance, must have captured the enthusiasm of young people; indeed, the Meeting permeated the whole City, from the Museum to the coffee-bars, and awoke Cardiff from its provincial slumber for a week. The accent on contemporary events in science, the challenges to accepted views thrown out by many speakers and the dynamic, friendly atmosphere contributed to the appeal of the programme. Strangely enough, perhaps because of the absence of white coats, the meetings seemed to recapture the climate of a time when science was still primarily a gentleman's hobby.

Attending the lectures at a Meeting such as this is a far more vital experience than merely reading a report in cold print. While the individual lectures provided fresh and interesting ideas, the general effect of the programme was to strengthen one's faith in science and to bring it within a human frame of reference.

I will probably not be able to attend another meeting of the Association for some years; it is unfortunate that there are not more opportunities to attend at meetings of this kind, but I expect I will keep in touch with the Association's activities by reading *this Journal*—in the Public Library, as its price makes it rather a luxury item for a student.

Area Committees

Two more Area Committees have been established since the May 1960 number of *The Advancement of Science*, in which the list of Committees was published. These are the Tay-side Area Committee and the Hull Region Area Committee.

The Tay-side Committee covers Dundee itself and Angus, Perth, Fife and Clackmannan. The Chairman is Dr. J. Iball, of the Department of Chemistry, Queen's College, Dundee, and Mr. Alex. G. Robertson, Director of Extra-Mural Studies at Queen's College, and Mr. A. W. Jeffery of Madras College, St. Andrews, are Joint Secretaries. The Committee lost no time in getting out their list of speakers and subjects, and have already given their first lectures.

The Hull Region Committee was launched at a meeting in Hull convened by Dr. Brynmor Jones, Vice-Chancellor of the University, on November 2. Dr. Edward Hindle, F.R.S., a former General Secretary, and Mr. W. H. Wilcockson, Chairman of the Sheffield Area Committee, represented the British Association. A powerful committee has been appointed, with Mr. B. N. Reckitt, of Messrs. Reckitt and Colman Holdings Ltd., as Chairman, Prof. G. F. J. Garlick as Vice-Chairman and Chairman of the Executive, and Mr. W. E. Styler, Director of Adult Education, as Secretary. The Committee's area will be that of the Department of Adult Education of the University, excluding the area of the Tees-side Area Committee in the north.

Junior British Association meetings are being planned by the Birmingham Committee for Easter, 1961, and the Sheffield Committee for the end of the summer term next year. The Sheffield plans are particularly interesting, as they include a number of 'excursions' to University Departments and industrial laboratories, as in the Annual Meeting itself. The Newcastle Committee are planning a Junior B.A. meeting for 1962.

Science Fairs

The Junior British Association meetings grew out of a desire to present lecture programmes of the same standard as those of the Young People's Programme in the Annual Meeting, but in different parts of the country and at times suitable for the local schools. Now the Science Fairs project has emerged from a desire to reproduce, in other parts of the country and at times suitable for the local schools, the very fine Science in Schools exhibitions which have been a feature of the Young People's Programmes at recent Annual Meetings.

The Association has received valuable assistance in this project from Dr. Watson Davis, Director of Science Service, of Washington, D.C., whose organisation has been arranging Science Fairs in the United States with much success for a number of years. Dr. Watson Davis attended the Birmingham Junior B.A. meeting at Easter 1960, and out of discussions then our Science Fair project crystallised.

There are differences between our project and the Science Fairs in the United States, which are based on sound considerations of the differences between the two school systems. Broadly, the B.A. project is that, so far as possible, the Fair should consist of exhibits from schools in an area, worked up by a group of pupils and demonstrated by them

for the period of the exhibition. The real value of this is the work done in the school, by the group, in preparing the exhibit; the fun of mounting and demonstrating the exhibit is the inducement. No prizes are offered, only certificates of participation; this is considered most important, for although imaginative presentation can do much to balance lack of resources, offering prizes would encourage those with resources to set a lavish standard with which others could not compete.

Two aspects of the group project, worked up by a number of pupils, are closely connected with other facets of the Young People's Programme. One is that a group may include pupils of different ages, and also pupils of different interests. For example, those with artistic ability can help with the display of a project, and those interested in history can undertake research into the past of the project. Many subjects will serve also to emphasise the scientific side of geography. The second aspect is that broadly-based projects of this sort may help greatly to bring together a number of fairly narrowly-based hobby clubs into one scientific society with many interests.

Science Fairs of this type would be visited by the schools participating in it, by parties from other schools in the area, and it is hoped by parents and other interested adults. The Fairs would present also a most valuable opportunity for cross-fertilisation of ideas for projects and techniques of demonstration. It is thought possible that, if space permits at the place where a Fair is held, there might be supplementary exhibits provided by University Departments or Technical Colleges, and by industry.

The Manchester Federation of Scientific Societies, with which the British Association is collaborating in the development of a lecture service for schools in Manchester and Lancashire, had the idea of organising a Science Fair quite independently. With characteristic generosity, they have invited the British Association to be associated with them in the first Science Fair of this kind, to be held in Manchester early in March 1961, in the Manchester College of Science and Technology. It is hoped that by then it will be possible to announce further developments of this new type of activity.

Generating Mathematical Insights

The Trustees of the Leverhulme Trust Fund have most generously made available to the Association £6,000 for the two-year programme of a Research Unit which has been established for the study of the generating of mathematical insights.

The basis for the study is the work which has been done in recent years by Dr. Z. P. Dienes, until recently of the Department of Mathematics at Leicester University, and Dr. Margaret Lowenfeld the eminent psychiatrist, each of whom has devised different but to a considerable extent complementary apparatus and techniques as an approach to the problem.

Dr. Dienes has had full support for his work from the Leicestershire Education Committee, who have provided facilities in their schools. Unfortunately Dr. Dienes has now left Leicester University, having accepted an appointment at Adelaide; but before taking up that appointment, he has been granted leave for a year to undertake some research at Harvard and also, through the grant made by the Leverhulme Trust Fund, to complete the application of his method up to G.C.E. level. The Leverhulme Trust Fund grant also makes it possible, again with the support of the Director of Education, Leicestershire, to examine the application of Dr. Lowenfeld's material in conjunction with that of Dr. Dienes and, it is hoped, finally to evolve a satisfactory 'marriage' of the two methods.

The British Association is glad to have been able to offer secretarial and administrative facilities, and to have brought these two highly imaginative approaches to a most serious problem together into one Research Unit, the creation of which has been received with keen interest and sympathy by a number of bodies and people concerned in this field.

THE PLACE OF PSYCHOLOGY IN THE SCIENCES AND THE TECHNOLOGIES*

By Prof. C. A. MACE *Department of Psychology, Birkbeck College, University of London*

Psychologists in recent years have been much concerned with establishing the position of their subject as one of the natural sciences. Some have stressed the concept of Psychology as one of the biological sciences, others have stressed the links with physics and engineering. The case is strong, and there are many in the senior natural sciences who would accept it as established. Perhaps indeed the time is ripe to take another look at the features in respect of which psychology differs from the other natural sciences. Some of these features help to explain why recognition of the subject as a science was for so long withheld. Other features may remain as complicating the theoretical issue of the 'unity of science', and complicating even more the practical problems of scientific education and the practical problems of the effective use of psychologists in technological research and development. In discussing the place of psychology in the sciences I shall be less concerned with theoretical issues than with the interests of parents and teachers who advise young people attracted to careers in psychology and the interests of those who employ psychologists in the public services and in industry.

Three peculiarities of psychology may be noted. (i) The subject has had an odd history and the present phase is of exceptional importance; (ii) It is the only subject in which the scientist himself is part of the subject matter of his science; (iii) Psychology is a subject in which the amateur has an essential role.

* This paper owes much to many people: to Prof. F. V. Smith of Durham; to Dr. G. C. Crowden, Professor of Applied Physiology at the London School of Hygiene; to Mr. J. D. Handyside, Controller of Research of the National Institute of Industrial Psychology; to Mr. Newbury, Director of Education at St. Helens; to Dr. Leybourne, Chief Inspector of Schools at Bristol; to Lord Halsbury; and to many others who have written in the *Advancement of Science* and elsewhere on various aspects of the subjects with which this paper is concerned.

The Historical Background of Contemporary Psychology

It is convenient to distinguish three major phases in the history of Psychology: (i) the Presystematic, (ii) the Systematic but Prescientific, and (iii) the Scientific.

The Presystematic phase is that of man's spontaneous reflections and speculations about his own nature and his place in the universe, reflections of poets, religious thinkers, philosophers, and men of action. The Systematic but Prescientific phase is that of the philosophy of mind as contained in the writings of philosophers from Plato and Aristotle to the present day. The Scientific phase is that in which knowledge of mind and behaviour is advanced by objective observation, experimentation and quantification. The story is complicated by the fact that the earlier phases persist and continue side by side with the development of the later phases. Presystematic and philosophical ways of thinking continue to feed material into the total corpus of fact, theory, speculation and superstition which is called Psychology. A large part of the work of the scientific psychologist consists in testing guesses, hunches and hypotheses which have their origin in presystematic thought, in sorting out sense from nonsense and superstition. In this Psychology is by no means unique. It took centuries for Physics to be distinguished from Metaphysics, Astronomy from Astrology, and Chemistry from Alchemy.

There is another interesting fact about the transition to science in Psychology. It is not

merely that psychology has become a biological science. It is also the case that the biological sciences have become psychology. Inquiries that are pursued by psychologists are also pursued by physiologists, neurologists, anatomists and zoologists. These other biological sciences have grown into psychology, and very understandably so. Physiologists in the past were chiefly concerned with the simpler functions of the organism such as growth, reproduction, the simpler sensory functions and the simpler modes of response. They have come to be interested in the higher functions, and the effects of environmental conditions upon the exercise of these higher functions, e.g. memory and thought. Zoologists were concerned chiefly with innately determined behaviour. They have come to be interested in the behaviour which is learned or acquired. Anatomists were preoccupied with structure. They now study structure in relation to function. All these biologists have in their own way become psychologists. So, too, in the physical sciences: electronic engineers and designers of computers have naturally come to be interested in the ways in which people think. Cybernéticians and designers of guided missiles have come to be interested in goal-directed, purposive behaviour. So they too in their own way have become psychologists. Psychologists have warmly welcomed all these distinguished cuckoos into the psychological nest.

The Psychologist part of his own Subject Matter

J. B. S. Haldane was among the first of the biologists to note (with some surprise and delight) that a scientist can be his own guinea pig. It had always been the situation of the psychologist that he was concerned with mental and behavioural functions in the form in which, and at the level at which, these functions are exercised and can be observed and experimented upon in himself. In observing the exercise of functions in himself the psychologist can often note with greater ease, with greater accuracy, and in a more enlightening way, facts which cannot be observed so well in other persons. In being his own guinea pig the psychologist can report in a way which no ordinary guinea pig could. This is surely an incontestable fact. It was demonstrated, for example, in a quite spectacular way, in the famous experiment of Head and Rivers* in 1908, who collaborated in performing a surgical operation which involved severing a sensory nerve and reporting upon the experience enjoyed during the process of regeneration. The experimental results suggested an important hypothesis concerning neural functions. Very much earlier examples could be cited. The classical theories of colour vision rest upon physiological *hypotheses* suggested by and tested by psychological facts—such 'subjective' data as phenomenological contrast effects, after images, etc. Topical examples could be cited—such as observation on the effects of mescalin, adrenalin, etc. The point to be emphasised is that the relations between psychology and the other biological sciences are reciprocal. It is not merely that physiological theory contributed to the explanation of psychological facts. Psychological facts are very often the basis of physiological hypotheses which again are tested by reference to further psychological facts. Unfortunately these simple and incontrovertible facts about the relations of physiological and psychological data have been interpreted in terms of metaphysical, epistemological and methodological theories concerning 'introspective' and 'subjective' data, from which psychology is only now in process of being disentangled. But disentanglement is almost complete. Psychologists and physiologists now work together unperturbed by behaviouristic or other philosophical ideologies.

The fact that the psychologist is part of his own subject matter carries the further implication that every man who observes himself objectively is in a way his own psychologist, and that he can contribute to scientific psychology. It has been said, and truly said, that much of the content of psychology has been 'creamed off' by poets or embodied in proverbs, in literature, and in the writings of philosophers. It is said, for example, that some of the important doctrines of Freudian psychology are anticipated in the works of Plato, in Diderot and Schopenhauer, that Joseph Butler's Sermon on Human Nature anticipated modern theories of Motivation such as that of McDougall, that Spinoza anticipated the concept of Homeostasis, that Samuel Butler and Bernard Shaw wrote with insight into the basic problems of evolutionary

* Rivers, W. H. R., & Head, H.: 'A human experiment in nerve division', *Brain*, 1908, xxxi.

theory. It is in consequence very seldom that a psychologist discovers something that is altogether new. Much of his time is spent in sorting out the more from the less promising hunches, and in finding fresh evidence for what has long been known in a rough sort of way, in giving quantitative precision to vague generalisations, and in drawing attention to exceptions to general rules.

The Role of the Amateur in Psychology

The fact that every man is in a position to observe himself and his fellow men gives to the amateur a distinctive and an abiding place in Psychology. Physics, electronics, or space-travel cannot be taken up as hobbies in which important discoveries are likely to be made. But in the biological sciences the case is different. Botanists and zoologists will for a long time to come encourage the amateur naturalists and travellers to record the behaviour of plants and animals, and to be on the look-out for new forms of life. Psychology has its human naturalists: playwrights, novelists, explorers, teachers, administrators and 'men of the world', all of whom have had 'experience' and enjoy 'experiences'. There will always be men who believe that psychological questions can be settled in discussion round the boardroom table or on a 'brains-trust' or in the correspondence columns of *The Times*. This fact may be distressing to those who think that psychology is a natural science pure and simple, and that all its problems can be solved only in the laboratory. The truth is that the 'amateurs' are not always lacking in perception or intelligence, and that the experience of some people in some walks of life does count for something. People write to *The Times* to say that our coins, our banknotes, our road signs are badly designed, that the Maternal State, dispensing orange juice to babies and mid-morning milk to children, is undermining the responsibility of parents, that delinquency and hooliganism are due to this or that, that the worker in that country is better motivated than the worker in this, and so on. On a rough estimate fifty per cent of the correspondence columns of the national newspapers is given to the discussion by physicists, poets and men and women of the world of questions with a clear psychological content. These questions are often discussed well. And so for a long time to come scientific psychologists will need to eavesdrop on Board Room deliberations, listen and look in to Brains Trust discussions and read the correspondence columns in the responsible press. And in this fact the scientific psychologist can find a point of technical methodological interest. Maybe 'Top People have the best hypotheses'. This is the point of methodological interest. Science it is said proceeds by the use of the Hypothetico-Deductive Method. The scientist takes some hypothesis, deduces from it some observable consequence and experiments, observes whether the facts are in accordance with the deduction. Yes, indeed; but there is no methodology for the production of hypotheses. The hypothesis selected may be just a wild guess, but it is better if it is a guess based on some kind of experience and some intelligent reflection on experience. This is where the philosophers, the poets, the Brains Trustees and the correspondents of *The Times* come in. Between them they throw up an immense number of hypotheses which might provide a basis for productive research.

These facts concerning the distinctive features of psychology as a natural science are relevant both to the problem of the effective utilisation of the psychologist in the social services, and in commerce and industry. They are also relevant to the education required to fit him for use in these services.

What is the use of a Psychologist?

Fundamental research is of course fundamental, but as a matter of history fundamental research and pure science have always grown out of technology. Mathematics was created to meet practical needs for measurement, Astronomy out of practical needs of navigation and forecasting, Physics and Chemistry out of the need to adapt material things to the service of man, Biology out of husbandry. So it is with Psychology. Its development as a science has been advanced by the demands of Service Chiefs in War, the demands of Education authorities, the Health Service and the demands of industry. Research begins in the Board Room out of questions raised by practical men. The Ivory Tower is at the far end of the Market Square. I cannot now attempt to illustrate this point by a review of all the fields of Applied Psychology. I will select only two: Ergonomics and Consumer Research. Both serve to illustrate

ways in which psychology is becoming integrated with other sciences and ways in which technology can lead to fundamental research. Ergonomics and Consumer Research are both concerned with the design of industrial products with regard to human needs. Ergonomics has been in the main interested in the physiological needs and basic necessities of life; Consumer Research has paid more attention to the 'psychological' needs, quasi-aesthetic needs, and the luxuries of life. These distinctions are very fine and relative. It is almost a law of human nature that luxuries become necessities. Ergonomicists and 'consumer researchers' could co-operate more than they do, to their mutual advantage and to the advantage of all concerned, in problems of design. There are principles common to the design of a pilot's seat, with a view to reducing stress or fatigue, and designing a chair in which the tired worker can relax before his television screen. They could co-operate in the study of the effects of noise on human performance having regard to the distinction between the noises that people cannot bear and the noises people like. They could co-operate in the study of all those situations in which boredom has to be distinguished from and related to fatigue. They could co-operate in the study of 'displays'. Clock faces and dials on dashboards cannot be designed once and for all, on the principles of visibility and legibility alone. New clock faces and new dials have to be designed to meet the demands of fashion, or the simple demand for something up-to-date and modern. The field as a whole is that in which a distinction can be drawn between what people want and what they really need. There is no rational basis for dividing this immense field of investigation between ergonomics and consumer research.

What has delayed co-operation between ergonomics and consumer research is the widespread impression that the latter is often content with less rigorous scientific standards, is often disposed to base inquiry on very dubious psychological theories, that the work is closely geared to advertising and sales promotion, and that in any case it has not yet made any important contribution to scientific knowledge. Even if all this were conceded, the fact remains that the field of consumer research is there, is an important field. There is no reason why ergonomicists should not apply their principles and techniques to this field. There is no reason why those engaged in consumer research should not increasingly adopt an ergonomic approach. The logic of the situation is such that both these things must inevitably come about. There are many ways in which this process of integration could be advanced. In the past, too, much time has been spent in the study of consumer preferences as between products which are indistinguishable on any physical, chemical or sensory test. It could be more rewarding to study the preferences for things which are palpably and sensibly different. There are fundamental questions, the study of which requires the combined resources of physiologists, specialists on nutrition, psychologists and sociologists. One of these is the relation between palatability and nutritional value. There are many questions which require also the specialist psycho-pharmacologist, e.g. the problem of the addictions. Very much more could be done than is done by or in the service of the food-producing industries. With the aid of the animal psychologists who have developed sophisticated techniques of cafetaria feeding and the design of feeding schedules fundamental knowledge could be obtained about the nutritional value and palatability of feeding stuffs for cattle, puppies and budgerigars. Consumer research in this field would have the advantage that with the animals themselves preferences are very much less affected by the advertisements and the pack. We need to know much more about changes in taste, acquired tastes, about fashion effects, and change of tastes with age. We need more systematic research into the longer term trends. Until recently consumer research has been largely a matter of *ad hoc* and unsystematic sampling. There are now, however, techniques for obtaining approximately random and representative samples of tastes and preferences in a population in a selected geographical unit. What is now needed is a corresponding technique for sampling the tastes and preferences of this population through time. It is *in principle* possible to plot and predict changes in tastes and preferences, movements of fashion, or slower changes, comparable in accuracy to the weather forecasting of today. Surely it would be of both practical and theoretical interest so to extend existing social surveys. It should be a point of interest to those who are now being stopped in the street or canvassed on their

doorsteps to know that they are at an observation point which one day will become part of an intricate 'meteorological' organisation for plotting the changes in the winds of fashion and of public opinion. Clearly, to do this would entail a substantial increase in 'scientific man power' with suitable training in psychology. It has been estimated that today (and including psychologists engaged in consumer research) there is not more than one occupational psychologist for every 250,000 of the working population.* If scientific consumer research were expanded to match that of the meteorological service, the number of psychologists employed would be impressively augmented. Add to this the needs of other branches of ergonomics, of occupational psychology generally, those of education, the health services, the Civil Service, and the defence services—all of which are becoming greater—the prospect of the expansion of scientific manpower in applied psychology raises problems of terrifying dimensions. It would seem that there are several uses to which a psychologist can be put. *But* we must distinguish two questions: (1) For what can a psychologist be used? (2) How shall he be used?

One principle may be noted. It would seem that the psychologist on his own, the 'pure' psychologist can be of little use at all. He who knows psychology only does not psychology know. The kind of psychologist for which the world has found most use is one who is first and foremost a natural scientist, one soundly grounded in the natural sciences as a whole, one who can work knowledgeably with other kinds of scientists, one who can work in 'operational' research units or as a member of an 'interdisciplinary' team—one, in short, who knows how to apply scientific method to those problems of management which are essentially psychological.

There is another principle, very much like unto the first: No psychological technologist, no technologist of any kind, can work on his own, or only with other technologists, but only in an organisation controlled and directed by administrative laymen or by a scientist who is a layman in regard to most of the activity he directs. The application of this second principle calls increasingly for some reorganisation of the administrative structure in which scientists in general are employed. There are many young psychologists in industry who are frustrated by the sense that those who direct their activities do not sufficiently understand or interest themselves in what psychology is about. They too frequently get the impression that 'Research Divisions' are created for reasons of prestige or as adjuncts to the sales and advertising section of the organisation. It is inevitable (and desirable) that the psychologist should work under the direction of a non-psychologist, and if he is to work to good effect, that those who direct his activities should be well informed as to what psychology is and what psychologists do. Lord Halsbury has recently drawn attention to the need for Boards of Directors to have at least one member with special responsibility for technological research, someone who has scientific qualifications. In the case of technological psychology, he requires the ability to distinguish between what is scientific and what is phoney, or at least should know when he has his doubts where to turn for reliable advice.

* This figure is suggested by Mr. John D. Handyside (Controller of Research of the National Institute of Industrial Psychology) in an address to the British Psychological Society.

The Basic Education of the Psychologist

Now with all these things in mind regarding the distinctive features of psychology as a natural science, the immensely varied fields in which it is applied and the rapid expansion in all these fields, the questions can now be raised: Where are all these psychologists to be found? What do they require in their basic education?

It is still not infrequently said that psychology is not a suitable subject for undergraduate education. If this were taken to imply that it should be *introduced* only in postgraduate courses this would be a *reductio ad absurdum* of the proposition. There is indeed much in psychology which could and should be learnt by boys and girls at school—in grammar, technical and modern schools.

But what? There is another widespread opinion often stated in tones of lament: that Psychology, as presented in the many introductory texts, is lacking in any agreed basic central or essential content. In this it is very unlike Physics, Chemistry, Engineering and the biological sciences.

There are I think simple and satisfactory answers both to the query and to the lament. Psychology is less suited than most other studies

both in the Sciences and the Arts for *specialisation* at the undergraduate level. He who knows psychology only does not psychology know. And this also is the clue to the answer to the lament. There is indeed no central and essential psychological content for all courses in psychology. What is essential and basic for the scientific study of psychology is a solid foundation in the other natural sciences.

The ideal first course for psychologists at the university is not a postgraduate course but a second first degree following a degree course in mathematics, physics, chemistry, engineering, physiology or other biological science. Almost if not quite as good is an honours course in psychology following a B.Sc. General Degree with or without Psychology as one of the science subjects selected. To avoid excessive extension in the length of university courses there is a need for some acceleration in science education in the schools. This is recommended on many grounds. The Director of Education of St. Helens has cogently argued that the transition from Natural History to Science should at least begin in the primary school, and there is little doubt that this could be achieved in the way he proposes. Certainly, if the education of psychologists is to be taken into account, both Natural History and Science could with advantage be more broadly viewed. There is something odd in teaching the young about waves of light and sound and then breaking off the story at the point at which physical stimuli impinge upon the organs of sense. There is something odd in teaching the young about the world of physical and chemical processes with but a cursory reference to the world of sensible colours, sounds, tastes and smells. There is something odd in science teaching which has so little to say about the physical bases of music and the other arts. At least these things would seem odd had we not been brought up to take them for granted. Natural history and biology could be enriched by interesting the young in the studies of ethologists of homing, migration and animal learning. Bird watching can be as uneducational as the spotting of engines. It can be very educational if it includes a little comparative psychology. After all, the transition from Beatrice Potter to Konrad Lorenz is not so great a leap that it could not be taken in the junior school.

I am not, of course, making a case for *systematic* psychology in school. Heaven forbid that the subject should be an option for the G.C.E. What *is* argued is that the science teacher of an accepted science subject should extend his range of interest and competence to cover topics in psychology closely bearing upon the subjects he teaches, that he should see to it that the Library is stocked with *suitable* psychological texts. Such a teacher would come nearer to being what has been aptly described as the 'Complete Scientist'. To train such scientists to the level of a good B.Sc. General Examination and to attract them to the schools would do more than provide within the schools the basic education of psychologists of the future. It would do something towards building the needed bridge, or one of many needed bridges, over the chasm that divides the Sciences from the Arts.

PHYSICS IN THE STEEL AND METAL INDUSTRIES

By M. R. HOPKINS *Department of Physics, University College of Swansea*

Introduction

Knowing and doing are distinct activities. The process of striving for completeness in the one and perfection in the other, even in a restricted field, is one which can never reach finality. Bertrand Russell has made the fundamental observation that the art of living is to learn to act effectively without complete knowledge. In coming to terms with this limiting principle we recognise that the odds against us can be shortened. The probability of effective action in a given situation is increased by a deeper knowledge of that situation. The problem of making the best use of natural resources becomes easier the better our understanding of the structure of matter and of the physical principles which govern its behaviour. The interest in discussing the role of physics in industry and in the steel and metal industries in particular is to try to examine to what extent this has taken place and to what extent it is likely to take place in the near future.

Metal Physics

The iron, steel and metal industries were in existence long before there was a coherent theory which accounted for the properties of metals. Metal physics, which forms part of the theory of solids, is an attempt to describe the observable properties of metals in terms of our basic ideas on the structure of matter. The main property which distinguishes a metal from a non-metal is that of high electrical conductivity, with which is associated high thermal conductivity. It is interesting that there is a sense in which we can say that most elements are metals. In fact, four out of five of the first ninety-two elements of the periodic table are metals. The ratio of the electrical conductivity of a metal to that of an insulator is remarkably high—for example, in the case of silver and fused quartz it is 10^{24}. It is natural that from the point of view of the theory of metals, conductivity is the property which has received considerable attention.

After theories had been put forward by Weber in 1875 and Riecke in 1898 the first important step was taken by Drude in 1900. His theory was essentially sound and although very important changes have been made in the light of later knowledge, it is still the starting point of any theoretical description of the electrical and thermal properties of metals. Drude assumed that electric current in a metal was carried by electrons and applied the dynamical theory of gases to the motion of the electrons. The theory was further developed by Lorentz. It was possible to derive the Wiedemann-Franz-Lorenz law which had been inferred from experimental results and which states that the ratio of the thermal conductivity λ to the electrical conductivity κ is a constant L times the absolute temperature T, i.e.

$$\lambda/\kappa = LT$$

Although the Drude-Lorentz theory successfully accounts for the Wiedemann-Franz law, which is confirmed in a general way by experiment, it gives rise to a serious difficulty. The specific heat of a solid is satisfactorily accounted for by assuming that the heat capacity is almost entirely due to the vibrations of atoms about mean positions. The Debye theory of specific heats, which is based on this conception, predicts results which are sufficiently well confirmed by experiment to warrant considerable confidence in its essential structure. The contribution made by electrons to the specific heat is very small. If the electrons in a metal obeyed the Maxwell-Boltzmann law of classical

statistical mechanics they would contribute substantially to the heat capacity of the solid and the agreement between specific heat theory and experiment would be destroyed.

The next great step forward was the direct result of the development of quantum mechanics in 192[illegible] and the realisation that to describe an electron as a particle was only justifiable in limiting cases in which macroscopic concepts were applicable. The motion of an electron in a metal was described by solving Schrödinger's equation for 'a particle in a box', and the allowed energy levels were shown to be discrete. In 1928 Sommerfeld showed that the energies of electrons in a metal were distributed according to quantum statistical mechanics and not according to classical statistical mechanics—the Fermi-Dirac distribution law rather than the Maxwell-Boltzmann distribution law. The Fermi-Dirac distribution law is derived by regarding electrons as having no individuality and by applying the Pauli exclusion principle, which states that no two electrons can have the same set of quantum numbers. This means that the maximum population of any energy level is two electrons having spins in opposite senses. This strict allocation of two electrons to each energy level, starting from the lowest, solves the outstanding difficulty of the Drude theory, for it is only the electrons near the top of the energy level system that can be affected by changes in temperature. The contribution of the electrons in a metal to the specific heat can only be very small compared with that of the atoms.

There is one fact which is not accounted for by the Drude, Lorentz and Sommerfeld theories. It is that some solids are metals while others are not. This difficulty is removed by dispensing with a simplifying assumption which is implicit in these theories—the assumption that the potential inside a solid is constant. Owing to the regular arrangement of the atoms, it is in fact periodic, and the effect of the periodicity is to divide the system of electronic energy levels into bands separated by ranges of forbidden energy. Our picture of a solid then is of a number of bands of energy levels separated by gaps. Starting with the lowest level in the lowest band, two electrons are allocated to each level. If the number of available electrons is such that the uppermost band which contains any electrons at all is completely full, the solid will be an insulator, because the application of a moderate electric field is insufficient to give an electron at the top of the full band enough extra energy to enable it to cross the gap of forbidden energy and occupy a level in the next band.

If the uppermost band containing electrons is only partly full, the solid will be a metal because the small amount of extra energy necessary to jump from one energy level to the one next above it within a band is easily acquired from an applied electric field.

The band theory of solids leads directly to a modern technological development of great importance, the manufacture and use of semiconductors and semiconductor devices. Semiconductors form a class of solids having properties intermediate between those of metals and insulators. They generally have conductivities which increase with temperature and usually owe their properties to small traces of impurity. Let us consider a solid which in its pure state is an insulator. There is an energy gap between the uppermost full band and the empty band above it. This empty band is called the conduction band. Suppose that the introduction of an impurity places an extra energy level (an impurity level) just below the bottom of the conduction band, and that this energy level normally contains electrons. An electric field will raise these electrons into the conduction band and the solid will conduct. The impurity levels in this case are called donor levels and the solid is known as an *n*-type semiconductor because the electric current is carried by negative carriers of electricity—electrons in the conduction band. The opposite type of semiconductor is one in which the impurity level, normally empty of electrons, is situated just above the top of the full band. Conduction then takes place by raising electrons from the full band into the impurity level. Such levels are called acceptor levels. In this type of conductor it is convenient to regard the current as being carried by 'positive holes' in the full band. A positive hole is a place from which an electron is missing and it can move through a crystal, under the action of an electric field, as a positive carrier of electricity. A semiconductor in which the current is carried by positive holes is known as a *p*-type semiconductor. The band schemes for metals, insulators and *n*- and *p*-type semiconductors are shown in Fig. 1.

The development of semiconductors has stimulated interest in the manufacture of single crystals of extremely high purity and techniques of purification, notably that of zone refining, have been established on an industrial scale. The junction of a metal and a semiconductor has rectifying properties which are of technical importance in metal rectifiers. The properties of junctions of *n*- and *p*-type semiconductors have given rise to the invention of the transistor, a circuit element with non linear characteristics, which is replacing the thermionic vacuum tube in many applications. The transistor has the advantage of not needing any filament heating current and also that of size. The small size of the transistor is of decisive importance in the design and construction of radio circuits which are to be used in circumstances entailing restriction of space, weight and power.

It is not unlikely that in the near future, electric circuits consisting of wires, coils, vacuum tubes, etc., will be replaced by a single piece of solid material suitably designed to perform the same functions. Other interesting applications of semiconductors arise from the fact that what are second order effects in metals are a good deal more pronounced in semiconductors. Thermoelectric effects are in this category and offer possibilities of useful application.

During the years in which the investigation of the behaviour of electrons in solids has led to a satisfactory explanation of conductivity and the development of semiconductors, a parallel investigation on the atomic scale has built up our knowledge of the crystal structure of solids. In 1912 and 1913, the work of Ewald, von Laue, W. H. and W. L. Bragg laid the foundations of the intensive study which has been pursued continuously since then, of the atomic arrangement in crystals by the method of X-ray diffraction. There are few fields which have yielded a richer harvest. The result is that present knowledge of the crystal structure of metals and alloys is detailed and comprehensive. Just after the discovery of wave mechanics and the recognition of the wave nature of the electron, Davisson and Germer and G. P. Thomson in 1927 showed experimentally that electrons were diffracted by crystals as waves having the wavelength $\lambda = h/p$ predicted by de Broglie, p being the momentum and h Planck's constant. There was this difference between electrons and X-rays: whereas the latter could penetrate deeply into the solid, electrons were stopped at the first few atomic layers. This meant that while X-rays provided the tools for the examination of the crystal structure of material in bulk, electron diffraction was the appropriate

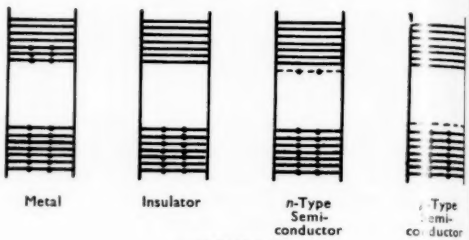


FIGURE 1.

method for the study of surfaces. Beautiful experimental work has been done in these fields. The electron diffraction camera has in turn been followed by the electron microscope which, owing to the small wavelength of electrons compared with visible light, has a higher resolving power than the optical microscope. The electron microscope has proved to be a powerful instrument in metallurgical research. It has also been of great value to biology.

There is a close connection between crystal structure and the band theory of solids. According to the latter the energy E of an electron in a solid is discontinuous for certain values of the vector wave number **k** of the electron. The magnitude of **k** is $2\pi/\lambda$, where λ is the de Broglie wavelength. If a beam of electrons is incident on a surface at a glancing angle θ the beam will be reflected if the Bragg relation

$$n\lambda = 2d\sin\theta$$

holds. n is an integer and d the spacing of the atomic planes. If the Bragg relation is expressed in terms of the wave number **k** it is seen to be identical with the condition that there should be a discontinuity in the energy E of an electron in the solid, which is obtained in a completely different way by considering the motion of an electron in a periodic field. If the electron has no home within the metal according to the band theory, then it will not enter it according to diffraction theory.

Just as the study of semiconductors depends upon the departure from perfection of a crystal, so does the understanding of plastic flow in metals depend upon the consideration of structural defects. From one point of view, a physical situation characterised by complete uniformity is sterile because there is no singular point from which change can originate. Theoretically, the shearing stress required to produce plastic flow in a perfect crystal is several orders of magnitude higher than that which is observed to deform a crystal in practice. In order to explain this it is necessary to postulate the existence of defects known as dislocations. There is ample experimental evidence, both direct and indirect, in support of this idea, which has been the means of achieving a fundamental understanding of the mechanism of plastic flow and related phenomena. Research in this field is proceeding at a rapid rate. The low observed values of critical shearing stress are explained by the movement of dislocations through the crystal lattice. A popular analogy is suggested by the observation that the movement of a small undulation from end to end of a rug lying on the floor is effectively the same as the movement of the rug as a whole. The idea that slip propagates over slip planes in a crystal by the movement of dislocations was published in 1934 by Taylor, by Orowan and by Polanyi. The two types of dislocations are edge dislocations and screw dislocations. The well-known film of the two-dimensional bubble raft model of Bragg and Nye gives an excellent picture of dislocations and the way in which they move. By modern methods in electron microscopy they may be observed in metals. Work on dislocations is not confined to single crystals. Our understanding of polycrystalline aggregates has been improved by the suggestion that low angle grain boundaries consist of arrays of dislocations. Other problems in which successful advances have been made include those of diffusion in metals and crystal growth. Progress is being made, not only in qualitative understanding but in quantitative prediction by considering dislocations singly and statistically.

Measurement and Control

The way in which fundamental research into the behaviour of matter leads to developments in industry is essentially of long-term significance. The main lines of investigation are not dictated by immediate industrial necessity, although research is often stimulated by practical requirements. A more direct way in which physics contributes to industry lies in the fields of measurement and control and in the use of physical principles in the analysis of large-scale processes. Measurement is necessary at the final stage of manufacture of a product in order to assess its quality and at earlier stages in order to ensure that the manufacturing process is operating satisfactorily. Difficulty may arise in various ways. The quantity to be measured may be ill-defined and traditionally assessed by those two well-known and oft-quoted instruments, the eye and thumbnail of the experienced workman. On the other hand, well-defined variables such as a linear dimension or chemical composition may have to be measured accurately under difficult conditions imposed by, say, inaccessibility, high temperature, or the necessity for rapid measurements.

The striking characteristic of modern industrial development is the emphasis on speed and continuity. This is well exemplified in the steel sheet industry where the older batch production methods have been superseded by continuous strip production. This has resulted in increased production, greater uniformity, improved quality and economy of human effort. An important feature of such a process is automatic control, based on the negative feed back principle. A measurement indicating departure from a pre-arranged value of a given variable is the signal which is used to correct the error. It would not be possible in a paper such as this to range over the whole field of non-destructive testing, or even to list the numerous interesting and ingenious methods of physical measurement which have been developed and incorporated into control systems. I will confine myself, therefore, to the rolling and coating of steel strip, in relation to which a great deal of important work has been done by the British Iron and Steel Research Association. (See, for example, the papers by Alderton and Hessenberg (1956), Sims (1958), Carlisle and Wilson (1958).)

In the continuous production of tinplate—steel sheet about a hundredth of an inch thick coated with tin a few hundred thousandths of an inch thick—the steel strip, after hot rolling, passes through a pickling line at 500 ft./min. and is then

reduced to the required thickness or 'gauge' by cold rolling at about 5000 ft./min. After annealing (at 1000 ft./min.) a further light cold rolling and cleaning, the strip is tinned electrolytically at 1000 ft./min. Automatic gauge control, i.e. the control of the thickness of the cold reduced strip depends upon measuring the thickness and using the indication of departure from the required gauge to correct the error by adjusting the setting of the rolls or the tension of the strip between successive pairs of rolls. There are several methods of measuring the strip thickness. First there is the mechanical method using the instrument known as the 'flying micrometer' which consists of a pair of rollers or lightly loaded rounded anvils bearing lightly on the strip, one on either side. The mechanical displacement of the rollers moves the core of a coil and the resulting electrical signal is amplified. Secondly there are radiation gauges in which a beam of X-rays or γ-rays is incident upon the strip. The proportion of the beam which is either transmitted or back-scattered depends upon the thickness of the steel. Either quantity may be detected and measured and the appropriate calibration carried out. The thickness of moving steel strip has also been measured by using a magnetic gauge. An electromagnet having an energising coil is placed under the strip so that the strip forms part of the magnetic circuit, the reluctance of which depends upon the thickness of the strip. Variations in thickness are detected by measuring changes in magnetic flux by means of a second coil wound on the electromagnet. The thickness of thin non-ferrous material has been measured by means of an eddy-current gauge. The magnitude of the eddy-currents induced in a sheet by a coil carrying high frequency current is, up to a point, dependent on the thickness of the sheet. The eddy-currents are detected either by their effect on the electrical characteristics of the original coil or of a second coil on the other side of the strip. Ultrasonic waves may be used to measure thickness of moving strip by a transmission method, similar to that used in the case of radiation gauges. Still another method involves the use of pneumatic gauges. The strip moves through the space between two jets, the variation in thickness producing pressure differences in the pipes which terminate at the jets. A method which has been used with success is the roll-force method which uses the rolling mill itself as the measuring instrument. The rolls of the mill are the rollers of a contact gauge, and the measurement depends upon the relation between the roll-separating force and the thickness of the strip.

The rapid measurement of the thickness of tin coating on steel strip is another problem. In an X-ray fluorescence method which has been developed, the surface is illuminated by an X-ray beam of wavelength chosen to induce fluorescence of the iron but not of the tin. The fluorescence coming back through the tin coating is attenuated to an extent which depends on the coating thickness. An alternative method is to measure the fluorescent radiation from the tin itself when it is irradiated by an X-ray beam of suitable wavelength. The thickness of zinc coating in strip-galvanising process has been measured by using a β-ray back scatter gauge, incorporating a Sr-90 β-ray source scanning the width of the sheet.

In automatic control systems the purpose of error detection is rapid automatic correction. As the result of experience, the interesting suggestion has been made that automatic control is not an end in itself but a temporary scaffolding which may be discarded once the sources of the variations which are revealed by its use have been eliminated by better understanding and improved design.

Some Examples of Measurements under Industrial and Laboratory Conditions

Finally, in giving some illustrative examples of physical measurements carried out under industrial conditions or in the laboratory, perhaps the writer might be allowed to choose one or two on the grounds of personal interest.

The first example concerns the measurement of surface finish. At one stage in the production of certain kinds of cold-reduced sheet, the roll surfaces are roughened by grit blasting before the rolls are set up. When the surfaces become smooth with wear, in a few hours, they are re-roughened. At a certain works a decision had to be made on the relative merits of pairs of rolls made by different manufacturers. The rolls made by one firm were found to retain their rough surface twice as long as those made by a second firm, when both were roughened to the same extent according to visual examination by experienced observers. The matter was important enough to be investigated in detail. Perspex replicas of the roll surface were

made and measured on a 'Talysurf' surface finish analyser, in which a finely pointed stylus traces the profile of the surface. The movements of the stylus are recorded, highly magnified, on a chart and also averaged to give a meter reading. In this way it was found that the visual examination was deceptive, and that the rolls which lasted twice as long were in fact twice as rough to start with. The remedy was to roughen both pairs of rolls to the same extent as judged instrumentally and not visually.

The second example is from a different field. When two, nominally smooth electrodes of an electrical contact are brought together into apparent contact over a substantial area, actual contact occurs only at a small number of very small areas where the current density is therefore sufficiently high to melt the metal. As the electrodes are subsequently drawn apart the current flows through one or more microscopic molten metal bridges. The erosion of low-voltage electrical contacts is a serious technological problem. Contacts fail to function because of the formation of a crater in one electrode and a 'pip' of excess metal on the other which may lock together. The investigation of the properties, formation and rupture of the molten metal bridge which forms between the electrodes to determine the role it plays in metal transfer between the electrodes is therefore of interest. The behaviour of the bridge depends upon the thermal and electrical properties of the electrode metal at temperatures outside the range of ordinary experience, for at its hottest point the bridge approaches the temperature of the boiling point of the metal.

It has been found possible to determine the ratio λ/κ of the thermal to the electrical conductivity as a function of temperature by observing an artificial bridge consisting of a short fine wire joining two large masses of the same metal. Measuring the temperature of the hottest part of the wire by matching with the strip filament of a pyrometer lamp, and measuring the potential across the conducting system at the same time, over a range of values of this pair of variables, enables λ/κ to be calculated from the relation

$$F^2(\theta_0, \theta_m) = 2\int_{\theta_0}^{\theta_m} \frac{\lambda}{\kappa} d\theta$$

where $F = V/2$, V being the potential difference across the conductor, θ_m is the temperature of the hottest point, and θ_0 the temperature at distances remote from the hottest point. θ_0 is effectively room temperature. By measuring the current at the same time it is possible to determine λ and $\varkappa$ separately, but in practice this is more difficult. The potential temperature relation is known as the ψ,θ relation because it is often expressed in terms of a generalised potential ψ to take thermo-electric effects into account.

The relation is independent of the geometry of the system but the condition for its validity is that heat lost by surface radiation should be negligible. This condition is fulfilled in a contact bridge and in the case of the short fine wire. In the case of some metals, e.g. platinum, the wire remains in place even when molten and measurements can be made well into the molten range (Hopkins, 1957).

The most satisfactory way of measuring the amount of metal transferred from one electrode to the other of a contact in operation makes use of the radioactive tracer technique which has demonstrated the part played by the circuit inductance even when this is extremely low (Llewellyn Jones, 1957).

References

Alderton, G. W., & Hessenberg, W. C. F. (1956): *Metallurgical Reviews*, **1**, 239.

Carlisle, S. S., & Wilson, J. H. (1958): 'Advances in Inspection Techniques as Aids to Process Control in Non-Ferrous Metals Production', *Institute of Metals Monograph No. 24*, 26.

Sims, R. B. (1958): Ibid., 5.

Hopkins, M. R. (1957): *Zeitschrift für Physik*, **147**, 148.

Llewellyn Jones, F. (1957): *The Physics of Electrical Contacts*. Clarendon Press.

THE DANGEROUS CONCEPT OF THE NATURAL FOREST*

By T. R. PEACE *Chief Research Officer, Forestry Commission*

INTRODUCTION

Relative to agriculture, forestry is still a very young science. Long after man had started to cultivate food crops on an artificial basis, he was still getting the timber he required from the exploitation of natural forests. Today, especially in Europe, forests are being continued or created on a large scale by artificial or semi-artificial means, but nevertheless the bulk of the world's timber still comes from natural, rather than artificial, forests. Thus while the agriculturist has no experience of the days when man gathered berries in the woods or edible leaves and grains in the prairies, and naturally tends to regard the few primitive peoples who still subsist in this way as incredibly backward, the forester can still see the magnificence of some of the natural forests untouched by man, and tends to use them as a measure against which to assess the success or failure of his own efforts. The contrast shows nowhere more clearly than in the field of selection and breeding. In agriculture, man has for centuries been selecting and breeding both his animals and his plants for increased production and better quality. Only in the last thirty years has the forester realised that the same could be done for forest trees.

There is no doubt that foresters endeavouring to establish or maintain artificial forests in Britain and in many other countries have made many mistakes. Unfortunately in forestry, mistakes are more long-lasting, and therefore more obvious, than in agriculture. Because of this, a school of thought has developed, which believes that such mistakes are in the main the result of departures from natural forest conditions, and which therefore advocates a return to such conditions in so far as they can be combined with timber production. This point of view has been expressed very cogently by Anderson (1956). Curiously, although he summarises his paper as being mainly a plea for more attention to 'the biological relationships between trees, litter, soil organisms and mineral soil', his main thesis is a very different matter, the basic desirability of the natural forest and a dislike of what he refers to as a 'mechanistic attitude' towards forestry. No one would deny the extreme desirability of more research into forest relationships. I, for one, would strenuously deny that it is necessary to assess the desirability of these relationships on the basis of their occurrence in the natural forest.

In a recent account of a visit to Switzerland, Reade (1960) has stated 'The Swiss attach great importance to knowing the type of natural forest which would develop spontaneously on their sites; they favour following the same basic pattern in commercial forests, in so far as it is reasonably practicable.' Indeed some foresters in Switzerland and elsewhere would be prepared to accept substantial temporary or even permanent losses in production, if these led to the restoration and maintenance of more natural forest conditions.

It is fashionable to refer disparagingly to 'tree farming', with the curious implication that farming has been unsuccessful or is in some way undesirable. The symposium on World Food and Population, which we are to hear on Monday, will no doubt stress that an alarmingly increasing world population can only be maintained by ever increasing advances in all branches of agriculture, which must therefore become increasingly divorced from the plant or animal in

* Address delivered to sub-Section K* (Forestry) on September 1, 1960, at the Cardiff Meeting of the British Association.

its natural environment. When the agriculturalist studies nature, it is mainly in the hope that by so doing he can advance further beyond it. In view of this, it seems appropriate to examine rather critically the idea of the inherent desirability of the natural forest, and to consider whether in fact this concept is doing more harm than good to the progress of scientific forestry.

The Definition of the Natural Forest

Before considering in detail the concept of the natural forest, it is desirable to consider what we really mean by this term. If we accept that natural forest is forest untouched and uninfluenced by man, we find ourselves contemplating a very wide variety of sites. At the best we have tall, closely-spaced trees, densely covering the ground, with regeneration only possible to extreme shade-bearers or when death or wind-blow make a break in the canopy. At the worst we have trees growing on sites so poor or so dry that a true closed community is never established, and all that exists is a sparse cover of stunted bush-like trees. In between these two extremes there are naturally all gradations. The natural forest will, by definition, consist solely of species which are native of the area, that is to say have reached it without man's assistance. Though occasionally natural species may occur in pure stands, they are usually found in mixture. The number of species involved becomes larger as we move south, until in the tropics most forests are of incredible botanical complexity. From the timber merchant's point of view the less complex stands are much more desirable, since it is easier for him to handle a single product. Indeed many of the very complex tropical forests have not been fully exploited, the most valuable species only having been removed. The natural forest, except occasionally where it has regenerated following forest fires, is almost invariably completely uneven-aged.

Few, if any, natural forests are completely stable. Gradual changes, often involving the replacement of one species by another, are taking place, though their progress is usually so slow that they are overlooked. Apart from the trees themselves, of course, there is a complex associated population of fungi, bacteria, insects and animals particularly in the soil, and this population is also subject to slow alteration. However such alterations in crop composition and in general ecology are so slow that the whole forest can be regarded as being in a state of biological balance, the so-called 'biocenosis', which is one of the most frequently quoted, supposedly desirable features of the natural forest.

The Artificial Forest

When man starts to manage a forest, and particularly when he creates a new forest on land not immediately previously occupied by trees, he inevitably introduces, to a greater or lesser degree, variations from natural conditions. He may, as in the prairies of North America, plant trees on sites the ecological climax of which appears to be a mainly herbaceous vegetation. He may, as with the deep peats of Scotland, afforest soils which have developed without tree cover into a condition in which they are certainly abnormal for tree growth. These are extreme examples, but it is clear that many of the soils on which forests are now being planted, and this applies particularly to Britain, are widely different from those on which natural forests would be likely to exist. Believers in the natural forest would argue that by appropriate treatment we might eventually bring the soils to something approaching natural forest conditions, but we must be prepared to examine critically whether this is really necessary or even desirable.

The mere fact of planting constitutes another point of difference from the natural forest, where all new trees arise either from seed or more rarely by suckering. The possibility of natural regeneration in forests already established is certainly one that merits more attention than it has received in Britain. It is already an established part of silviculture in many Continental countries. There is some evidence, not very well established, that trees which have grown *in situ* from seed are under some conditions more wind-stable and possibly more resistant to root diseases, such as *Fomes annosus*, than are planted trees. On the other hand, natural regeneration precludes change of species, and prevents the introduction of new or improved strains, resulting from greater attention to seed sources and from the work of tree breeders.

In the natural forest, the young tree has to struggle for its existence with other trees and with competing vegetation. This has the effect of eliminating the weaker trees, but it does not

necessarily follow that the survivors are the best trees from the forester's point of view. They may be the most vigorous, but may well be of less desirable species, of poor timber quality, branchy or crooked. In addition the retardation of growth consequent on this early competition may lengthen the rotation required for the trees to reach merchantable size and thus have an appreciable economic effect. Normal forest management, involving planting at relatively wide spacing, and subsequent removal of competing weed growth, ensures the survival of most of the trees until the first thinning.

In the natural forest no timber is removed, trees remain standing until they die and decay. All the tree, leaves, branches and trunk is eventually returned to the soil. In the managed forest, thinning and eventually felling, whatever method be practised, results inevitably in the removal in the timber of some of the chemicals extracted by the tree from the soil. This removal is not in fact, on the same scale as that which happens in agriculture. Trees do generally make more efficient use of the soil than most farm crops, by extracting more from it per year; but more is returned in leaf and twig fall than is commonly the case with completely harvested agricultural crops. In addition to the removal of some of the nutriment from the soil in the course of timber harvesting, the presence of cut stumps of live trees provides a condition which is absent from the natural forest and which has proved in some areas a grave source of danger. Such stumps are particularly suitable for colonisation by *Fomes annosus* and other root fungi, which can thence spread to and decay or even kill neighbouring standing trees. However nearly the forester may try and approach to the natural forest he cannot avoid the creation of felling-stumps.

In some cases the forester must, and in many cases he does, plant trees which are not native. In Britain for instance our only native timber conifer, Scots pine, is not only unsuited to many of the sites we wish to afforest, but surpassed in rate of growth by other conifers on many sites where it could be used. For these reasons large areas in Britain have been planted with exotic conifers, such as Sitka spruce, and Japanese larch. Even in countries where the native tree flora is much richer than in Britain, exotics have often been planted, because they promised greater production, or widened the range of sites which could be afforested. Even the most enthusiastic advocates of the natural forest would probably admit a limited use of exotics, preferably in admixture with native species, in countries where the native tree flora was notably lacking in productive timber trees.

It has already been pointed out that natural forests tend to be mixed. For simplicity both in treatment and in utilization the planted forest tends to be of a single species. This so called 'monoculture' has been one of the main targets for those who believe that forestry has been moving in the wrong direction. It undoubtedly introduces certain risks, which I shall discuss later.

The Improvement of Forest Sites

The natural forest is essentially in a relatively stable condition, to which little is added and from which little is taken away. There may be a gradual transference of chemicals from the underlying rocks to the soil above, aided by the action of tree roots; some chemicals may be leached either to levels below root penetration or out of the area altogether in moving water. In most cases such changes are very gradual, and rapid soil alterations, such as occur when forest is clear-felled or even in the course of establishment of some artificial tree crops, are certainly rare. In the natural forest, improvement or deterioration, whichever is taking place, is normally too gradual to be readily observed. In managed forestry on the other hand rapid intentional improvement is possible, as well as, it must be admitted, rapid unintentional deterioration, showing in its worst form as soil erosion in some of the hotter parts of the world. Site improvement can be particularly spectacular when we consider areas not previously carrying trees. On many heath and moorland sites, establishment of trees would be almost impossible without initial ploughing and phosphatic manuring. But when these operations have been carried out, establishment, at any rate, becomes relatively easy. We are now coming to realise that on some sites manuring at a later stage may be necessary if we are to grow timber crops. Beyond this, the possibility of increasing production by manuring, so long accepted in agriculture, but so long regarded, on very little evidence, as uneconomic

in forestry, is now attracting attention. There is no reason to believe that we have reached the limit of forest site improvement that can be economically effected.

The Improvement of Forest Crops

It is now accepted by most foresters that improvements in rate of growth, straightness, branchiness, timber quality, etc., can be made by selection and breeding. This ability to improve may be exercised at successive levels to increasing degrees by choice of species, by choice of provenance within a species, by selection of seed stands within a provenance, and finally by the selection of individual trees and breeding from them. This last introduces the possibility of hybrid vigour and of combining desirable factors not hitherto present in the same tree.

Such improved strains could of course be used to establish near-natural forests, but their large-scale introduction into forestry would certainly be easier under more artificial systems of forest management.

THE CONCEPT OF THE NATURAL FOREST IN MODERN FORESTRY

Exotics

It is generally and very rashly assumed that native trees will occur naturally in the environment that best suits them. In fact, examination of the full distribution of a tree normally discloses that it grows really well only in parts of its range, and that elsewhere, because of limiting soil or climatic conditions or because of competition with other species, it is less successful. It is rash to assume that the optimum growth within its range is the best growth of which it is capable. The belief that trees are desirable within their natural range and undesirable outside it, entirely overlooks the bases of plant distribution. It is quite clear that no tree, since it evolved, has had the opportunity to colonise all the regions that would be climatically possible for its existence. Barriers of mountain, of climate, or of sea have limited most trees to ranges far smaller than they are now achieving by the hand of man. Perhaps the outstanding example is Monterey pine, *Pinus radiata*, which occurs naturally on a single peninsula in California, but is now being grown successfully in all temperate regions where the winter temperature is not too low. Naturally there is much less chance of failure in using a native tree within its known range, than in using such a tree as an exotic outside it. Until we have more exact information on the soil and climatic needs of different species, foresters are likely from time to time to plant them where they will not grow or are only able to grow badly. The behaviour of Corsican pine in regions with low summer temperatures and of European larch of high alpine origin in most parts of Britain are cases in point.

Nevertheless, wholesale condemnation of exotics, such as that expressed by Boyce (1954), who said, 'Exotics are not all foredoomed to failure, but for every exotic the chance of failure is much greater than the chance of success', are obviously untrue if viewed in the light of the highly successful use of species such as Sitka spruce, Norway spruce, Lodgepole pine and Douglas fir in British forestry. In this connection it is illuminating to observe the superior growth of North American Lodgepole pine as compared with native Scots pine on many sites in northern Scotland.

There is obviously an increased disease risk in the use of exotics. In their native country they are likely to have reached a state of balance with the existing pathogens. In a new environment they may be subject to attacks by pathogens to which they have had no chance to develop resistance. If planted under unsuitable conditions, they may prove to be abnormally susceptible to pathogens which would not otherwise trouble them. Larch canker, associated with *Dasyscypha willkommii*, is particularly serious in Britain on larch of high alpine origin, and *Brunchorstia destruens* attacks Corsican pine weakened by unsuitable climatic conditions. Occurrences of this kind, however, are not in fact limited to exotic trees.

Pure and Mixed Crops

The reasons for the comparatively frequent use of monoculture in British forestry are outside the scope of this paper. It is sufficient to say that most of the forest area in Britain consists of pure blocks, sometimes of considerable size. A change over to real mixed planting, as apart from marginal planting with other species, which is often done for amenity or fire break-purposes, would involve a major change in British silvicultural methods.

By now we understand many of the difficulties, silvicultural and pathological, which occur with pure plantations, we know little of those associated with mixed ones. Since we cannot seriously assume that mixed stands, being more 'natural' than pure ones, have no problems, we would be rash to embark on large-scale mixed planting, until we have more knowledge of the advantages and disadvantages associated with it. There is certainly need for more research on this subject.

Monoculture has been so frequently condemned that it is scarcely necessary to quote references, but the objections to it have been ably summarised by an American committee on silviculture (Anon, 1939) and later by Boyce (1954). The main arguments put forward are that a pure stand of any species constitutes a disease risk, and that a pure stand of conifers leads to soil deterioration. It has also been suggested that mixed stands are more wind stable (Werner & Ärmann 1955). There is truth in all these contentions, but they are not universally true, and even when they are operative, it does not necessarily follow that they outweigh other, especially economic, advantages of pure crops. The question of soil deterioration will be considered later. With regard to disease it must be admitted that a pure stand provides ideal conditions for a pathogen to build up to epidemic proportions, since it can pass directly from tree to tree. It must be remembered, however, that this will apply also to a mixed plantation, if the pathogen involved is one affecting all the species used. In any case components of mixed stands can become very severely diseased. Chestnut blight, caused by *Endothia parasitica*, probably the most devastating forest tree disease yet encountered, did most of its damage to chestnut in mixed stands. Spruce bud worm, a very serious pest in Canada, is just as damaging on spruce growing in mixture with fir as it is on pure spruce.

Inevitably the attack of a pathogen in a mixed stand, where only one species is susceptible, will appear less than in a pure stand of the susceptible species. In fact more careful observation might disclose that the severity of attack on the individual tree was the same in both cases. Sometimes in mixed stands a diseased species may be suppressed by the healthy trees of other species around it. In a pure stand the same degree of attack might only lead to a depression in growth rate, the less attacked trees at any rate surviving to form a crop. This also can lead to errors of observation. Larch canker is said to be worst in pure crops of European larch. In fact it is more likely that in mixed plantings European larch has only survived the competition with other species when it was not attacked by canker. As a high light-demander it can only survive if it establishes a certain degree of dominance over the trees of other species around it. In stands where, owing to canker, it has been unable to do this, it has disappeared from the crop.

In some cases mixtures may benefit a pathogen by enabling a fungus or insect to attack species which would otherwise remain free. An example of this is *Fomes annosus* acting as a killing agent. Hardwoods are normally resistant to this fungus, but when they are grown in mixture with conifers the fungus is able to spread from the stumps of the conifers and attack them. Honey fungus, *Armillaria mellea*, behaves in the reverse way. It normally only attacks conifers when it can spread to them from hardwood stumps.

Many Continental foresters have advocated mixed stands as the best prevention of attacks by the root and butt-rotting fungus, *Fomes annosus*, claiming with some justification that its attacks are less serious in natural stands. They have failed to observe that the regular thinning, which is so much a part of the treatment of pure, even-aged managed crops, provides the stumps which are necessary for invasion and subsequent spread by *Fomes*. It is now known that this can be prevented by appropriate treatment of the cut surfaces of the stumps to stop *Fomes* infection. Orłoś & Dominik (1959), however, condemn even this practice, solely on the grounds that it is unnatural.

In a few cases, admixture may directly increase disease. This is the case with some of the rust fungi, which require two different host plants for their development. For instance, *Melampsora* rust on the leaves of poplars becomes much more severe when they are planted in mixture with or immediately adjacent to, larch which is the alternate host of this fungus.

The behaviour of the Larch needle-cast fungus, *Mycosphaerella laricis*, on the Continent illustrates particularly well the complex effects of mixtures on disease. In pure stands, infection normally takes place in the spring from fallen needles on the

forest floor. If the larch is in mixture with spruce, some of the larch needles remain suspended on the spruce branches during the winter, and are thus much nearer to the emerging larch needles in the spring and therefore more favourably placed to infect them. Thus in mixture with spruce, the larch tend to be more badly attacked. On the other hand, if the larch is planted in mixture with beech, the leaves of the latter, which fall later than the larch needles, tend to cover them on the ground, and thus partially prevent infection in the spring, with a consequent lessening of attack. Even apart from the disease angle, there is no reason to assume that mixtures will always be beneficial to the component species. For instance, Norway spruce is quite frequently damaged by drought when growing in mixture with more efficient water absorbers, such as ash or oak, when neighbouring pure spruce stands remain unharmed.

Boyce (1954) goes so far as to say that the chances are strongly against the long-term success of pure stands, unless the species concerned forms such stands in its native habitat. This ignores the fact that a species growing naturally in pure stands may do so solely because it lacks efficient competitors in the area which it has so far colonised. Equally, a species growing naturally in mixed stands may do so because evolutionary chance has placed it in a region where capable competitors are also present.

Nearly all agricultural crops are more liable to disease than their wild counterparts, but nevertheless without exception they produce higher crop yields under modern farming methods. It is often suggested that this is due mainly to modern disease control techniques, which for economic reasons and because of the large areas involved may not be applicable to forest conditions. It seems reasonable to suppose, however, that we can discover methods of control suitable to the forest and less expensive than those used in agriculture and horticulture. In any case there is as yet little evidence in Britain that pure planting has led or is leading to any major pathological disasters.

Uneven-aged Stands

The natural forest tends to be uneven-aged, since young trees spring up in the gaps left when old ones die or are blown down. Efforts, often quite successful, have been made, particularly on the Continent, to reproduce artificial forests of this type by group fellings followed by regeneration or planting in the gaps thus created. Inevitably, unless the groups are very large, the trees in such forests, tend to produce shorter boles and larger branches than even-aged stands. They demand very skilled marking and, at any one felling, produce has to be collected from a very large area. From the amenity angle they are certainly attractive, and there is little doubt that many foresters have come to regard them as desirable largely because they look so nice. They attract the believer in the 'natural' forest, because they are clearly more like it. If one does not accept the inherent desirability of natural forest, it is hard to find many arguments for their retention, let alone for their development where they do not already exist. Possibly the strongest argument is that uneven-aged stands may be more wind-stable than even-aged (Köstler, 1956). This is clearly a matter that requires further investigation.

Forest Soils

Many of the arguments in favour of the 'natural forest' are based on the supposed effects of more artificial methods on the soil and on the soil fauna and flora. As a pathologist I cannot claim to speak with any authority on the difficult and complex subject of forest soils and the effect of forest treatments on them. Nevertheless this aspect of the 'natural' forest argument is so often advanced that I must attempt as best I can to deal with it.

Firstly, it is frequently claimed that pure stands of conifers lead to podsolisation, that is the leaching of minerals from the surface layers of the soil, and to the formation of deep layers of raw humus. Though further work is needed, both these suggestions are certainly substantially true. It remains to be discovered whether they are really so damaging to tree crops. Under these conditions conifers will often make the bulk of their roots in the supposedly undesirable humus layer, which certainly normally provides them with a good water supply, and, judging by their rate of growth, with a sufficiency of nutriment; though on some soils this may have to be supplemented if a timber crop is to be produced. It must be admitted that the wind stability is often poor with such shallow-rooted trees.

A good example of the bias that the belief in the inherent virtues of the natural forest can bring into scientific investigation is given by the very useful work of Grosskopf (1950) on tree roots. Grosskopf studied the distribution of the fine roots of various species in the soil, and found that some species, such as oak, effectively penetrated much deeper than others and were therefore better able to absorb nutrients from the deeper layers of the soil. These he regarded as properly accommodated to the site, while shallow-rooted trees, such as spruce, were classed as site-antagonistic. This classification is certainly worth further investigation, both of the long-term effect of the trees on the soil, and of the extent to which successive economic crops of the so-called site-antagonistic species can in fact be raised. But the dangerous bias of preconceived ideas is shown by his statement that it is native species which are able to root deeply and exploit the soil properly this apparently being based on the fact that, in the area where he worked, spruce was an introduced species. The use of 'native' and 'exotic', instead of species or soil type, to explain the differing rooting behaviour is clearly unnecessary.

The growth of conifers and even of some hardwoods is often perfectly satisfactory on highly podsolised soils, and it can hardly be claimed that podsolisation alone is a bar to economic forestry. Much more research is needed here, but it should not start with the assumptions that podsolisation and humus formation are *a priori* undesirable.

When we consider the soil fauna and flora, we are on even more difficult ground, for we are involved with a little understood complex of organisms some progressively breaking down the litter, some living in the soil, and particularly in the rhizosphere, the area immediately adjacent to the roots, and some in and on the roots in the form of mycorrhiza. It is the normal and supposedly desirable balance of these organisms in the natural forest which is usually referred to as biocenosis.

It is perfectly clear that a forest started on virgin ground, as has been the case with so many of the British forests, will start without many of the organisms that would be present in a mature forest, and possibly, though this is much less certain, with some that are undesirable. It is equally clear that certain pathogens are initially absent from such soils. *Fomes annosus*, which only appears when unprotected stumps are made available for its colonisation, is an important instance.

The fact that mycorrhiza are known to perform absorptive functions and thereby do sometimes aid the tree, has unfortunately led to a feeling that they exist for this purpose, and even to a belief that their presence under all circumstances is not only beneficial to the tree, but necessary to the maintenance of its good health. While this view is grossly exaggerated, there is nevertheless abundant evidence that under some circumstances, and particularly in nutrient deficient soils, they do exercise a very beneficial influence (Björkman, 1944; Rayner, 1947; Gilmour, 1958).

Most plants seem to acquire mycorrhiza in the nursery or at an early stage by infection with aerial spores. In any case, it is now well established that mycorrhiza are only necessary for tree growth under certain circumstances of restricted nutrition. This being so, there is no sound basis for some of the complicated stories of lack of mycorrhizal balance in unnatural stands which have been promulgated on the Continent. Orłoś & Dominik (1959), for instance, have suggested that *Fomes annosus* particularly attacks trees planted on agricultural soils because the necessary protective mycorrhiza are absent. The work of Rishbeth (1950) and other observations in Britain by Low & Gladman (1960) suggest, however, that the severe attacks of *Fomes* on old agricultural land are associated in part with the past use of lime and the resultant high pH, which may act by discouraging *Trichoderma viride*, a competitor with *Fomes* on the surface of tree roots.

DISCUSSION

It is clear that the natural forest is worthy of considerable study, since it provides an example of trees and their accompanying organisms established in a relatively stable and balanced environment. As such it may well give information of value for managed forestry. It becomes dangerous only when it is elevated to the level of a concept of desirability, as an example which foresters should endeavour to copy. Used in this way it can lead, and has led, to the adoption of practices, not because they will give enhanced and sustained

production, but merely because they appear relevant to this unthinking ideal.

I have tended above to stress particularly those instances where silvicultural practice based on the attributes of the natural forest, such as mixed species, mixed ages or the use of native species, may lead to worse rather than better growth. In so doing I have certainly tended to give a biased picture of their general effect. This is perhaps inevitable, since the main purpose of this paper is to stress the danger of adopting the concept of the natural forest as a basis for silviculture, instead of founding it on a scientific consideration of each set of conditions without initial bias for or against any particular practices.

There has always been a tendency in a growing and imperfectly understood science, such as forestry, to enunciate at an early stage general principles, which it is hoped may serve as signposts through the fogs of ignorance. Biologically at any rate, such a procedure is almost invariably dangerous. The interactions of organisms with one another and with their environment are so complex that what appear at an early stage to be rules, may merely be coincidences. At present we lack the necessary basis for any embracing simplifications. If we are to make progress in the acquisition of the knowledge that is so necessary for a proper understanding of forest processes, it is dangerous to limit ourselves at this stage by the enunciation of general principles, even if they appear to have a moderately sound foundation. To burden ourselves with a concept as vague and ill-founded as the inherent desirability of the natural forest is doubly dangerous.

References

ANDERSON, M. L. (1956): 'Some biological aspects of forestry', *Quart. J. For.* **1** (4), 278–89.

ANON (1939): 'The relation of stand composition to crop security' (Report of the Committee on Silviculture, New England Section, Society of American Foresters), *J. For.* **37** (1), 49–54.

BJÖRKMAN, E. (1944): 'Om skogsplanteringens markbiologiska förutsättningar', *Svenska SkogsvFören. Tidskr.* **42** (5), 333–55; *For. Abstr.* **8** (1), No. 61.

BOYCE, J. S. (1954): 'Forest plantation protection against diseases and insect pests.' F.A.O. Forestry Development Paper, No. 3, 1954, 41 pp.

GILMOUR, J. W. (1958): 'Chlorosis of Douglas fir', *N.Z. J. For.* **7** (5), 94–106.

GROSSKOPF, W. (1950) 'Bestimmung der charakteristischen Feinwurzel-Intensitäten in ungünstigen Waldbodenprofilen und ihre oekologische Auswertung', *Mitt. Bundesanstalt f. Forst- u. Holzwirtschaft* No. 11, 1950, 19 pp.

KÖSTLER, J. N. (1956): *Silviculture*. English trans. by M. L. Anderson. Oliver & Boyd, Edinburgh. 416 pp.

LOW, J. D., & GLADMAN, R. J. (1960): '*Fomes annosus* in Great Britain, an assessment of the situation in 1959.' Forestry Commission: Forest Record No. 41, 22 pp.

ORŁOŚ, H., & DOMINIK, T. (1959): 'Z biologii huby korzeniowej—*Fomes annosus* (Fr.) Cooke', *Sylwan.* **104** (1), 1–13.

RAYNER, M.C. (1947): 'Behaviour of Corsican pine stock following different nursery treatments (*Pinus nigra* var. *calabrica* Schneid.)', *Forestry*, **21** (2), 204–16.

READE, M. G. (1960): 'Lessons from Switzerland', *Quart. J. For.* **54** (2), 111–26.

RISHBETH, J. (1950): 'Observations on the Biology of *Fomes annosus* with particular reference to East Anglian Pine Plantations. I. The Outbreaks of Disease and the Ecological Status of the Fungus', *Ann. Bot.* **14** (55), 365–83.

WERNER F., & ÄRMANN, J. (1955): 'Stormfällningens dynamik—en studie', *Svenska SkogsvFören. Tidskr.* **53** (3), 311–30; *For. Abstr.* **18** (4), No. 4167.

THE ROLE OF THE UNIVERSITIES IN TEACHING TECHNOLOGY

By Prof. M. W. THRING, F.R.S. *Dept. of Fuel Technology and Chemical Engineering, University of Sheffield*

1. Pure and Applied Science

If I were to attempt definitions of Engineering and Applied Science, I would say that Engineering is the attempt to provide accurate design formulae based on appropriate empirical measurements, and Applied Science is the attempt to provide rough-and-ready design formulae based on fundamental principles. The Engineering approach is essential if one is to cut down the factors of safety in design, and the Applied Science approach is essential if one is to strike out into new fields where empirical formulae are not available. The two processes are thus supplementary, and it is the aim of the Universities in teaching technology to give men a good grounding in both Engineering and Applied Science. They must understand fully the relation of industrial processes to fundamental science, such as, for example, nuclear theory, metal physics, or chain reactions, so that if they are presented with new and strange problems they will have an idea how to set about them, but they must also be able to do accurate and intelligent design for what might be called classical engineering processes, such as the design of a steam turbine or boiler.

I have found the diagram of Fig. 1 to be very useful in clarifying the relations between pure and applied science. The vertical scale on this diagram represents the level of fundamentality or quality of thought involved in a subject, while the horizontal scale is divided into pure and applied science; that is to say, according to the aim of the thought. Pure science is that concerned with inquisitiveness, and applied science that concerned with the benefit of mankind. The top left-hand square represents superficial pure science or what might be called natural history; the sheer classification and description of events without any theory as to why they occur or any fundamental grouping. The square below this, that is, fundamental pure science, corresponds particularly to the *experimentum crucis*, the experiment designed to decide whether A's theory or B's theory is the nearest to the correct description of reality. The top right-hand square is the *ad hoc* solution of industrial, agricultural and medical problems. 'Suck it and see' is the old description of this type of empirical work. The bottom right-hand square, fundamental applied science, is the job of the research departments of University engineering and applied science departments. It can perhaps best be described as the evaluation of the coefficients in the differential equations describing the processes going on. These processes may be the fission process in the nucleus of a U-235 atom in a graphite moderated pile, or the physical chemical reactions of combustion, or the purely physical process of turbulence in flow in a complex system, but whatever they are, fundamental applied science has to develop the importance of the different terms in the differential equations, and eventually give them numerical

	Pure Science	Applied Science
Descriptive	Natural History Empiricism	Ad hoc Solution of Practical Problems
Fundamental	The Experimentum Crucis	Coefficients in the Differential Equations

Fig. 1.—Pure and Applied Science.

values. At certain stages in the history of technology there has been a tendency for industry to be interested only in the top right-hand square, and for the 'ivory-tower' academic scientist to be interested only in the bottom left-hand square. This is probably why, in the mind of the public, a confusion has arisen between the horizontal and vertical co-ordinates so that they have not realised that it is possible to have fundamental applied science just as it is possible to have superficial pure science. Fundamental pure science and fundamental applied science differ in their aims but not in the quality of thought used.

Education is, unfortunately, riddled with snobbishness and it is vitally important that in all educational establishments the tendency for the humanities to regard themselves as superior to pure science should be overcome. Pure science in its turn has to overcome the tendency to regard itself as superior to engineering and applied science. It is true that the pure scientist has a single-minded vision in that he is looking only towards the question of inquisitiveness, he wants to know how things happen for the sake of knowing. The applied scientist on the other hand has a permanent squint. One eye looks continuously with the aimless inquisitiveness of the pure science, the other eye is directed across it towards the benefit of mankind. The applied scientist is trying to help people to have a better standard of living in relation to the available resources on the earth's surface. Something like 80 or 90 per cent of the students who come to the University to the Pure Science Faculty finish up in industry as applied scientists. Probably the most important problem of all in this country at the moment is to relate the choice of subjects of schoolboys and girls going to the University to the national needs in careers after they leave the University. At present the main reason why a boy chooses a subject at a University is either because it is a subject he has already learned at school, or because a master at school has encouraged him in this subject. Since practically no applied scientists go in for teaching, because industry needs far more than the supply, there is obviously a very great failure in feed back in this direction.

The only valid snobbishness in education is that which relates to the quality of thought. It is very unfortunate that this snobbishness has got confused with the historical snobbishness based on the subjects which were most useful to get a man a job in the Middle Ages.

2. Training for Careers

Fig. 2 shows diagrammatically the main channels by which schoolboys and girls pass through to their careers in the outside world. It illustrates the point that the only career which contributes directly to the primary production on which the nation lives is that in industry, so that the most important channels are those leading to the trained man's contribution to the improvement of industrial processes and products. We have got rid of the old snobbishness that a man who did nothing useful in his life was superior to the one who earned his living by his contributions to production, but the relics of it still linger in our educational system.

The figure also illustrates how many boys go to Pure Science Departments at the Universities and finish up with careers in Applied Science.

The essential problem therefore is how are we to show the brightest schoolboys that applied science is worthy of their talents and can give them a fascinating career. The creation of the colleges of advanced technology does not solve this problem, but it does of course increase the channels by which such boys can develop their talents on their way through into industry. A simple illustration of this problem was given by a recent example when a boy was sent to our Department of Fuel Technology and Chemical Engineering at Sheffield University with a letter from his Headmaster that said that he was not very bright, and therefore not good enough for pure science, but would do very well no doubt in technology. This type of snobbishness will certainly prevent Britain taking her place in the technological advances of the twentieth century, although she managed to lead in the nineteenth century because there was sufficient life and intelligence among those who went straight into industry to develop many new ideas. In America industrial management will very often scrap plant just because something newer has come along, even though it would be economic to retain the old plant for some time. In Britain, on the other hand, the tendency is the other way. We keep old plant because we are fond of it when it would be economic to spend money on developing

new plant and then installing it. This is why we are also very weak on development work in industry. The whole trouble arises because the brightest boys, those with the finest minds and the most intellectual drive, are not going via a technological training into industry and then rising to the boards of management where they could impress new views on the firms.

a good University degree if we do not teach them at all, but merely refer them to some text-books, but the problem is how can we present the material in such a way that it will excite and interest the next 5 per cent who are potentially honours degree men, but who have not been kindled by the teaching at school, or by their parents, or by their contacts with practical problems.

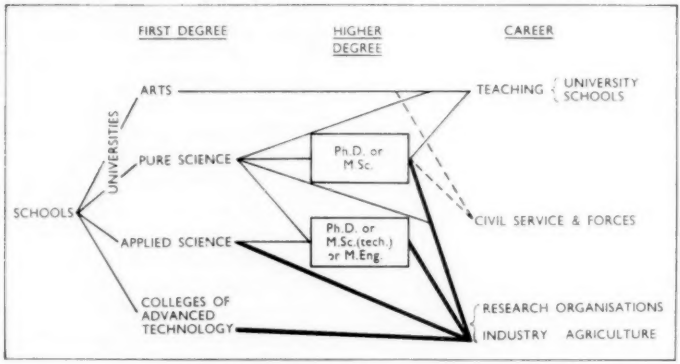


Fig. 2.—Training for careers.

3. The Dynamic View of University Teaching

There are plans to increase the number of University undergraduates up to 5 or 6 per cent of any age group, and these plans bring out clearly the two quite distinct views of the role of Universities in teaching. The first of these views might be called the static view. This is that a certain proportion of the youth of any year have inherently an intelligence level which will get them an honours degree at a University, and the rest have not.

All that the University has to do is to sieve them out according to their inherent level of intelligence. As soon as one looks at teaching from the point of view of the undergraduate who is taught, one realises how completely false this view is. Whether an undergraduate does well in his exams. or not depends more on whether the subject has been taught in a way which has aroused his interest and enthusiasm than it does on his inherent level of intelligence. There is combustible material in the minds of a large proportion of our youth, and the problem is to get the spark to it which will kindle it into a full blaze. This is the dynamic view of University teaching. The top 1 per cent will get

I do not think anyone in a University would be bold enough to claim that he could lay down a formula for such dynamic teaching, but it is clear that the medieval methods which were ideally designed for instilling a knowledge of Greek and Roman literature cannot be ideal, when we have the much more concrete problem of making fundamental scientific laws seem exciting and interesting to a large proportion of our youth. Some parts of technology have an inherent glamour which largely does their work for them. The nucleus and the electron are obvious examples, and even the combustion chamber of a rocket is not difficult to glamorise. On the other hand, the combustion of a particle of pulverised coal in a large boiler, or the behaviour of steam in a turbine is more difficult. The blackboard and chalk still have their place in University teaching, but colour films, television programmes, working models, and working diagrams can all be used a great deal more than in the past. We have, in our Faculty, a strong view that no class should be larger than fifty, since the relation between the teacher and the taught is weakened if there are too many students at a great

distance from the teacher. Similarly, supervision or tutorials in very small groups of not more than three are very valuable if there are a sufficient number of postgraduate students or other qualified people to carry them out. The maximum number of hours of teaching in the week must not rise too high and undergraduates and postgraduate visits to industry and other organised events are a great help. Simple research or design study problems in the third year, where the student feels that he is doing something that no one has ever done before, are also valuable, provided they can be fitted in without absorbing too much time. The dynamic concept of University teaching has a long way to go, but there is no doubt at all that modifications in teaching methods will be necessary as the Universities expand.

4. The Role of Research in Applied Science

It has long been realised in many fields that an organisation which attempts to stand on one leg only is doomed to failure in the long run. Thus, industry must manufacture goods for sale, but it must also be doing development work on new goods and new materials, and new processes for making old goods. Similarly, the research associations must do research and application. Even a pure research institute will run down and stop having new ideas after about twenty years if it does nothing but research. The same principle applies both to the pure science and the applied science departments of Universities. If they do nothing but teaching, their teaching will grow out of date and uninspired after about twenty years. On the other hand, if there is an active research school in the same department, then their teaching is constantly fed back with new ideas and principles, and, conversely, their teaching feeds the research school with subjects on which the frontiers of knowledge have not yet been reached. I can never prepare a lecture on any subject without thinking of several research problems that are not yet solved in this subject. In applied science the Universities must do research of the type which I have described in Fig. 1 as fundamental applied science, that is, essentially filling in the coefficients in the differential equations that describe the complex mixture of processes occurring in industry. If I may give an example of this from my own subject, we have developed a method of studying the combustion of a fuel whether it is an oil vapour, oil drops, or particles of pulverised coal, under conditions where all the fuel moves through a combustion chamber in exactly the same way so that we can vary the conditions with complete control. When we apply this method to pulverised coal, the question arises should we study pulverised pure carbon, or should we study a much more complicated real coal with a high volatile content such as in industry? As an applied scientist, I say that we should study the type of coal which will be used in industry because we are just as much interested in finding out the differential equations for this, which will be useful, as we are in finding out whether the diffusional or chemical reaction control theory for combustion rates is the more correct one. The latter would be the job of a pure scientist.

Thus, an active research school is an essential part of a University applied science department, not only because it feeds back original teaching and receives ideas for new research from the teaching, but also because a good proportion of the graduates will be much more valuable to industry if they have learned to be self-propelling in research after the completion of their undergraduate course which has taught them to be self-propelling in learning. We attempt, in training a man for a Ph.D., to bring him to the point where his director in industry will be able to say to him, 'Go away and solve this problem and come back to me with the answer'. This does not mean that he will attempt to do anything so silly as to solve it by his own unaided efforts but he will be able to find out who can help him when he is stuck, whether for a mathematical solution or for a practical construction.

5. The Role of the Universities in Teaching Technologists other Subjects other than Technology

When professors of technological subjects are tackled on this question they always retort that the average University-trained technologist knows more about all the arts subjects than the average arts man knows about technology, and this argument can certainly be supported. Nevertheless, it is obviously true that the Universities are proud of the reputation they have for broadening the basis of a man's education and that they must continue to do as much on these lines as possible,

and in many cases more than in the past. It is not possible to have more compulsory examinations than at present, indeed there is a tendency to overcrowd the technological courses because so many pure science subjects must be taught to a good technologist and, if anything, the courses require simplifying and streamlining. Hence, the technologist must learn about other subjects which will make him a good citizen by methods outside his formal teaching curriculum. These methods can of course be many—some voluntary lectures are already given at the Applied Science part of Sheffield University on such things as English Literature, and the attendance has been quite reasonable although they have been held during the lunch hour. Evening lectures, debates and other formal arrangements are of course also valuable in this connection, but there is no doubt that the finest method of all is the method which has grown up spontaneously at the older Universities of small groups of undergraduates collecting in each other's rooms for arguments over coffee in the evening. Since the civic Universities are now definitely committed to the task of catching up with the older Universities in the quality of their educational system they must do a great deal to develop this particular activity. It is likely that as the Civic Universities grow larger they must adopt the better features of the college system of the older universities in order to divide the students up into smaller groups than those represented by the University as a whole and by the Union. The more or less compulsory dining together of all the students of one year in one college is obviously also a very desirable feature as this forces them to meet their contemporaries out of the comparatively small group and it is thus an easy matter to go off and have a good argument after a meal. The Civic Universities must introduce culture to the technological students by subtle voluntary methods, since the student cannot stand any more compulsion. However, I think one must take it as axiomatic that such broadening of education is a vital part of University training.

WHAT THE OCTOPUS MAKES OF IT; OUR WORLD FROM ANOTHER POINT OF VIEW

By **M. J. WELLS** *Department of Zoology, University of Cambridge*

If one is to find out how the brains of animals work one must first discover what they are built to do. At the highest, vaguest level it is easy enough to define this; brains sort out sensory information and deal with the organisation of suitable reactions. At any more detailed level we run into trouble because we have to define, among other things, the sensory information that is being used and this is not as easy as it would at first appear to be. By examining the properties of the sense organs that an animal has—by recording off sensory nerves and so on—we can discover only the limits within which the animal is potentially capable of detecting changes in the world around it. What we cannot find out by such a study is whether the animal actually makes use of all the information provided by its sense organs—that is whether the creature's performance is limited by the properties of its sense organs or by the integrative machinery of its central nervous system.

To discover this we have to watch and experiment upon the intact, living animal.

The account that follows deals with the deductions that can be made from observations of the behaviour of individuals of one particular species —the common octopus. It will be shown that in this animal it is the central integrative and not the sensory machinery that limits what the animal can do—a fortunate state of affairs since the very nature of the limitations that we find gives us important and otherwise unobtainable clues about the way that the integrative machinery must itself be put together.

As an experimental animal the octopus has a number of outstanding virtues. It is easy to catch and easy to keep. It eats crabs and pieces of fish, both of which are easy to get. And its habits in the sea, where it lives among rocks in a hole whence it pounces out on passing prey, mean that we can keep it under comparatively natural conditions in the laboratory.

Octopus also has the advantage of being of the right order of size. This is important if we are to investigate the properties of its central nervous system, because it means that the animal is living in the physical environment to which we are ourselves accustomed. We can devise tests for the animal knowing that it will be operating under conditions that we ourselves understand—a situation that is not always true of invertebrate animals, particularly of very small invertebrate animals, in whose lives surface tensions and molecular forces generally assume an importance altogether foreign to our own experience of the world. By studying *Octopus*, an animal of about 1/100th of our own size, we avoid problems of this nature and, because we can ourselves appreciate, measure and classify most of the environmental disturbances to which our experimental animal reacts, we can hope to build up a picture of what the world looks, tastes and feels like to it. This animal has sense organs capable of detecting very much the same sorts of changes as our own, yet the picture of our world that an octopus must have can be shown to be very different from ours in several important ways that can only be due to fundamental differences in the make-up of its central nervous system.

Octopuses are primarily visual and tactile animals, like ourselves. The similarity of cephalopod and vertebrate eyes is often cited in textbooks as a classic instance of convergent evolution, the eye of an octopus being structurally so like the vertebrate eye that sections of it are a favourite catch-question in university scholarship examinations; it has a lens, iris and retina arranged very

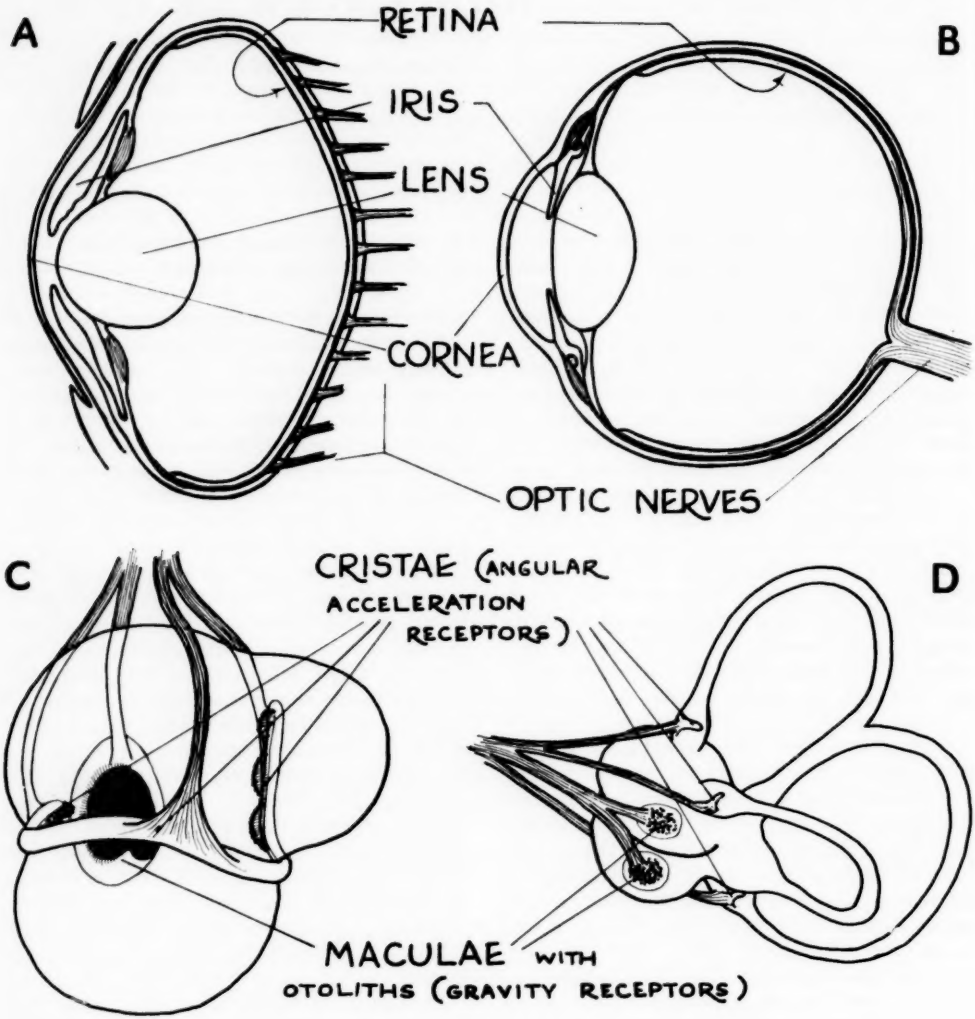
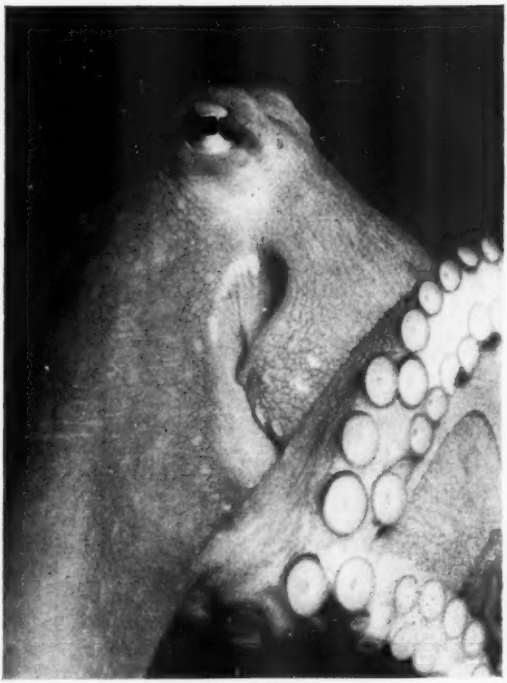


Fig. 1.—Parallel development of sensory receptors in man and the octopus. *(a)* and *(b)* are longitudinal vertical sections through the eyes of an octopus and a man respectively. *(c)* and *(d)* show the statocyst of *Octopus* and the labyrinth of the inner ear of man. *(c)* is adapted from Young (1960), *Proc. roy. Soc.* B, **152.**

much as in our own eye (Fig. 1; see also illustration A). In detail, of course, the two differ both in function and in structure; focusing, for example, is by moving the lens in and out in *Octopus*, by altering the shape of the lens in man; the optic nerves depart from the outside of the retina in *Octopus*, from the inside (and out through the 'blind spot') in ourselves. The important point for present purposes is that the octopod eye is capable of furnishing very much the same sort of information about things seen as our own.

Octopus has no specialised olfactory organs. There is a small pit with sensory cells in it behind and below the eye, which has been claimed as homologous with the olfactory 'osphradium' of marine snails, but since removal of this pit produces



A. *Octopus vulgaris* Lamarck. An intelligent animal with sense organs capable of providing very much the same sorts of information about the outside world as our own. From training experiments we can build up a picture of what the world must look and feel like to it, and thereby discover something about the organisation of its central nervous machinery. (*Photograph*, M. J. W.)

Octopus has one other set of sense organs showing a remarkable convergence with our own. The octopod statocyst (the animal has two, one on either side of the head just below the brain) has an otolith hung on a set of sensory hairs (which we can compare with the macular gravity receptors of our own inner ear) and a line of sensory cells with loaded processes arranged in three planes at right angles inside a fluid-filled sac—an arrangement that is clearly capable of providing the same information about angular accelerations as the ampullae in our semi-circular canals (Fig. 1).

no noticeable defects in the animal's behaviour its function remains problematic. Much more important is the chemical sensitivity, a 'taste sense', which seems to be a property of the body surface generally and especially of regions such as the rims of the suckers which are particularly well supplied

with sensory nerve endings. The sense organs concerned are difficult to identify; there are very many sensory nerve terminations in the skin, and some at least of these, buried below the surface, may be discounted as more likely to be mechanoreceptors reacting to compression or stretch than chemoreceptors. But others, with free endings projecting to the surface of the skin, may well be responsible for the animal's sensitivity to chemical substances in the water around it. The little we know about these structures tells us practically nothing about the nature of the information that they must provide; the nerves from them are too small to record from electrically with techniques at present available and we are forced to deduce their function from a consideration of the sort of stimuli to which the animal can be shown to react.

As well as this equipment for collecting information about the world around it, *Octopus* must have sense organs for telling it what is going on within its own body. It must, among others, have sense organs recording tension in the muscles of its arms, since it reacts to passive stretch by contraction; and in any case it is difficult to see how the animal could make the continual fine positional adjustments needed for clambering over the rocks among which it lives were there not some source of detailed information about the position of parts of the individual arms. It will be noticed that proprioceptive sense organs, though wholly internal, are nevertheless potentially capable of giving information about the outside world because the distribution of tension in the individual muscles must bear some relation to the surfaces over which the animal is travelling and to the shape and weight of any objects that it handles. We ourselves can distinguish the shape of objects by touch because we are aware of the relative position and movements of our fingers—we use proprioceptive information from receptors in our finger muscles and integrate this with information from more superficial tactile receptors in order to build up images of objects that we are handle.

Examination of the sensory equipment of *Octopus* gives us, then, some idea of the potential capacities of the animal—what it ought to be able to do were it able to use all the information collected to best advantage. Potentially it is a very capable animal indeed. It has flexible muscular arms, with suckers for grasping and manipulating objects and a set of sense organs capable of providing very much the same sorts of sensory information as our own. In principle there is no reason why this animal should not be capable of carrying out manipulative acts much as we do.

Yet it does not. Its brain is not organised to deal with the incoming sensory information in as elaborate a way as our own. It has several notable differences in organisation—deficiencies by our standards—that limit the integrative capacity of the animal so that the perceptual world that an octopus lives in is a very different place from our own.

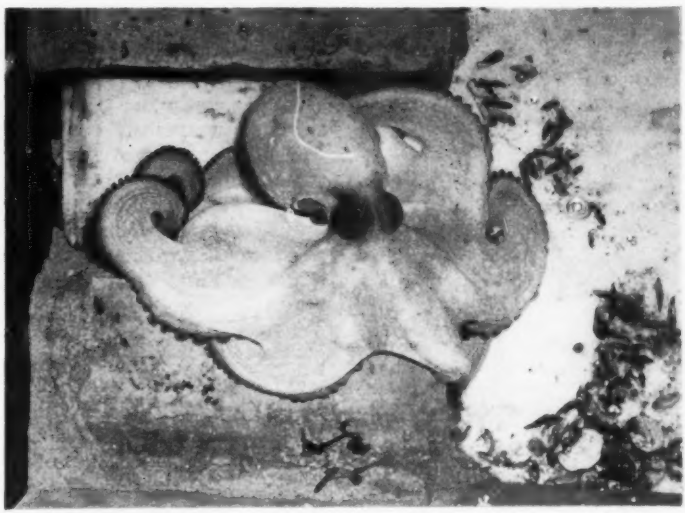
We can find out a little about this other world by watching octopuses in aquaria. The animal likes to sit in one corner of its tank, preferably amongst a heap of rocks or bricks. From this 'home' the creature pounces out upon any small moving object; it will attack fingers dabbled in its tank (Aristotle said this showed it was a very stupid animal), and it collects food such as crabs or pieces of fish when these are dropped in, taking them home to devour at leisure. The octopus, looking out from its home, is clearly able to distinguish both the size and the range of objects that it sees. Large objects are not attacked, and very large objects elicit a special display (illustration B) in which the animal expands the interbrachial web, pales and flattens out, appearing suddenly much larger than it really is—one can assume that this serves to deter would-be predators in the sea. We can tell that size is distinguished as a quality of objects independent of the extent of the image that they make on the retina because small objects are recognised as such even when very close to the octopus, and animals that have been trained (see below) continue to discriminate between figures of similar shape but different size regardless of their distance.

Objects of different shape are also distinguished, and untrained octopuses, fresh from the sea, are more liable to attack some objects than others. All will attack crabs when they see them, and most individuals will go for a variety of less 'natural' figures—geometrical shapes cut out of card and moved about on the end of a wire—generally preferring circles to rectangles, and elongate figures moving along their long axes to similar figures moving at right angles to their long axes.

Observations of this sort do not, however, tell us

very much about the limits of the visual discrimination system, and very little about the way that objects seen are classified by octopuses. The fact that an animal reacts in the same way in two situations does not necessarily mean that it cannot distinguish between them. More probably it simply has no reason for doing so, and in order to pursue the matter further we have to provide incentives which will drive the creature to discriminate if it possibly can.

With many invertebrate animals this would be difficult. *Octopus*, however, is intelligent and readily trainable. It is also perpetually hungry (an octopus will eat sufficient to double its weight in a month if it is given the chance) so that it quickly learns to recognise any situation that yields food. If, for example, a crab and a geometric figure are shown together in its tank, the animal learns in three or four trials to come out and attack when the figure is shown alone. The difficulty is then to prevent the octopus from attacking all figures indiscriminately, and this can be done by punishment for attacks in inappropriate situations. Octopuses dislike small electric shocks, and a convenient form of punishment is a 6–9 volt A.C. electric shock, administered by touching the erring octopus with electrodes fixed to a probe. Using this reward and punishment technique octopuses can be taught to distinguish between a variety of figures. As one might expect some discriminations prove more difficult for them than others; they take longer to learn these, and the accuracy of their performance never becomes as great as with simpler discriminations. We can use the number of errors that octopuses make in learning to discriminate as a measure of the difficulty of the problem set to them and by training to distinguish between objects that differ in only one definable way at a time we can discover which features of things seen are discriminable. We can, for example, show that octopuses are capable of distinguishing between figures that differ only in orientation, provided that the difference between the figures can be defined in terms of horizontal and vertical—mirror images are not distinguished (Fig. 2). Such a result tells us a number of things about the way



B. A startled octopus. If suddenly confronted by a moving object larger than itself, *Octopus* pales and flattens out, expanding the web between the arms. This makes it look bigger than it really is, and the effect, which is heightened by expansion of the chromatophores to make large dark rings around the eyes, presumably serves to deter would-be predators. (*Photograph*, M. J. W.)

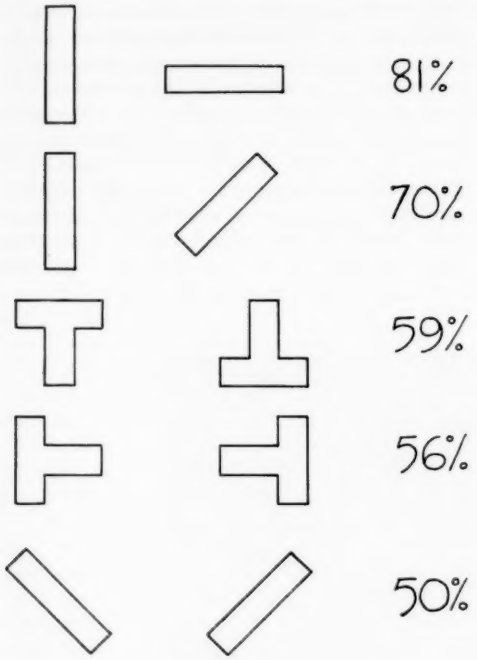


Fig. 2.—Geometric figures that octopuses can be trained to distinguish by sight, and the proportion of errors made over the first sixty trials of training to discriminate between them (from Sutherland (1957), *Nature (Lond.)*, **179**).

that the animal's visual system must be organised. It shows, for example, that the octopus is *not* making use of any of the available 'short cuts' to discrimination—it is not distinguishing shapes because they differ in area or because they differ in length of outline or because they have more or fewer corners (cf. insects such as bees, which classify shapes by their degree of irregularity of outline). *Octopus* must, in fact, be discriminating between objects much as we do, from the distribution of their masses in space. Apparently classification of shapes is in some way related to their distribution about the horizontal and vertical axes, since forms, such as the oblique, mirror-image rectangles of Fig. 2, which have similar distributions about these axes, are not distinguished. It is interesting that we, too (though possibly for rather different reasons), find mirror images and left/right relatively difficult to distinguish compared with horizontal/vertical and up/down.

Recent work has shown a possible anatomical basis for the octopus's tendency to classify objects in terms of their horizontal and vertical extents; the elements of the retina itself, and the connections between the individual nerves in the outer layers of the optic lobes of the brain are both arranged in a predominantly horizontal and vertical manner. The retinal array can be said to be horizontal and vertical (rather than simply arranged along two axes at right angles) because the eyeball remains constantly oriented with respect to gravity over a wide range of bodily positions (Fig. 3). It can be shown moreover that this orientation depends upon the integrity of the statocysts, and that after surgical removal of these gravity receptors the majority of trained animals cease to discriminate between figures differing only in orientation. A few individuals, however, continue to discriminate between the objects, though not always in the direction learned during preoperational training, and some animals make many more than random errors, consistently mistaking vertical for horizontal rectangles (and v. v.) in their postoperational training. This result was at first puzzling—a statocyst that is not there clearly cannot be producing the wrong information—until it was noticed that the perverse animals were all individuals that habitually sat in positions such that their retinae (as indicated by the angle of the slit-like pupils) lay at right angles to the position maintained during preoperational training. Evidently the orientation of an object can be distinguished because the image of the object falls in a constant relation to the horizontal/vertical axes of the retinal array and the central machinery for learning to recognise figures is organised on the assumption that the eye remains in a constant position with respect to gravity.

By vertebrate standards this is a very curious way of doing things. Vertebrates, such as ourselves, recognise the orientation of objects whatever position the eyes happen to be in; our central nervous system correlates proprioceptive information about the position of the eyes relative to the head, and of the head relative to gravity, with the distribution of the image on the retina. Vertebrates can still tell which way up they are and recognise the orientation of figures after destruction of the

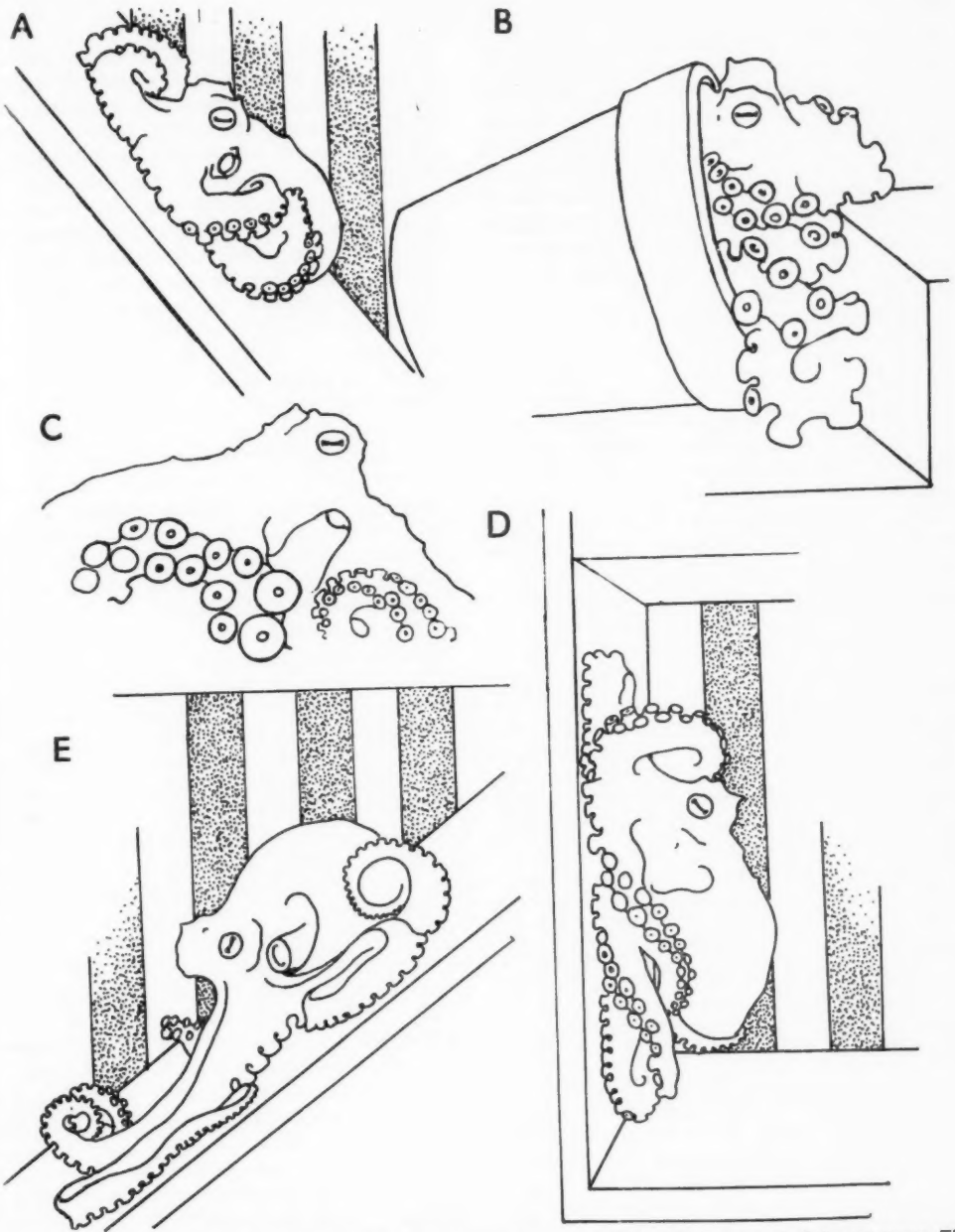


Fig. 3.—Orientation of the eyes of *Octopus* before ((*a*), (*b*) and (*c*)) and after ((*d*) and (e)) removal of the statocysts. The slit-like pupil normally remains horizontal over a wide range of bodily positions, but this constancy of orientation is lost when the statocysts are removed (from Wells (1960), *J. exp. Biol.* **37**).

gravity receptors in the labyrinth, presumably by integrating proprioceptive information about the distribution of tensions in their muscles with the visual input. This is something that octopuses cannot do. Although operated animals continue to feed and grow after statocyst removal, they never learn to orientate themselves correctly, and do not regain the capacity to discriminate between objects differing in orientation, although they can still learn simpler discriminations, such as between black and white discs.

A return to the question of non-use of proprioceptive information in learning will be made below in consideration of the tactile system of *Octopus*. But first, what else can the animal discover about the world around it by using its eyes?

The question of whether octopuses can distinguish colours has been investigated but remains unsettled. It certainly looks as though *Octopus* can distinguish colours, but none of the conditioning experiments done so far have eliminated the possibility that the experimental animals were really distinguishing the coloured lights or objects on a basis of intensity of illumination rather than wavelength of transmitted or reflected light. A similar difficulty occurs in the interpretation of results which suggest that octopuses are able to distinguish another quality of light reaching the retina—its plane of vibration. Recent experiments with octopuses in aquaria show that they can be taught to distinguish between sources of light polarised in two directions at right angles—sources that look exactly alike to us. It has been claimed that this capacity is related to the fine structure of the retinal elements and that these detect the plane of polarisation directly—in which case the ability to learn the distinction presumably rests once again upon the constant orientation of the retinae. Alternatively, however, it is quite possible that the octopus is *not* detecting the plane of polarisation directly, but making the distinction indirectly from differences in the pattern of reflections from objects in its tank and from particles suspended in the water. In any case the use, if any, that *Octopus* makes of its capacity is unknown.

As might be expected, if only from the animal's excessive number of arms, *Octopus* has a well developed touch sense. We can investigate this systematically in much the same way as for the visual senses—by reward and punishment training experiments. The only differences in the technique arise out of having to use animals blinded by section of the optic nerves (a simple operation carried out under urethane anaesthesia) in order to eliminate the possibility of their learning to recognise the test objects by sight. The test objects are presented one at a time, by touching them against one of the arms of the octopus; the animal then grasps and either accepts the object, passing it in under the interbrachial web to the mouth, or rejects it, thrusting the object away. When it is rewarded for accepting one of a pair of objects, and punished for accepting the other, an octopus rapidly learns to discriminate between them (Fig. 5).

It is possible in this way to train octopuses to distinguish between shellfish of various species, and between live and dead shellfish of the same species—the dead ones being scrubbed clean and filled with sealing wax. Octopuses are thus able to make tactile discriminations on a basis of 'taste' alone—we can call this a 'chemotactile' sense—using receptors on the arms.

The chemotactile sense is difficult to investigate, but not because the animals are difficult to train. The difficulty arises rather from our own inability to measure and classify the stimuli—and until we can do this ourselves, we have very little hope of finding out how the octopus does it. It seems that the chemotactile sense organs on the arms of *Octopus* are sensitive to tastes that we would call sweet, bitter and sour (not salt—the animal lives in the sea), but we do not know whether these tastes are alike to the animal. We do know that the sensitivity of the receptors is very high, the suckers on the arms detecting substances in concentrations comparable with the minimum concentrations detectable by the human tongue. And there the matter must rest until we can devise a practicable means of measuring the concentration of substances at the region of contact with the suckers of the octopus and a way of ensuring that our test objects continue to taste the same throughout the experiment.

It is easier to investigate *Octopus*'s ability to distinguish the physical properties of objects touched because it is easier for us to classify and control the size, shape and texture of objects than their chemical characteristics. As in the visual experiments we can measure the similarity of any

two objects to octopuses from the proportion of mistakes that they make in learning to discriminate between them. Doing this we discover something rather curious about the organisation of the tactile system of *Octopus*. It turns out that the animal is quite unable to distinguish the shape of objects, or indeed to distinguish anything about them other than their surface texture and even this is rated in a rather curious way. It seems that the animal can detect the presence of surface irregularities, but cannot distinguish anything about their distribution. The members of the series of objects shown in Fig. 4, for instance, were only distinguished when they varied in what could be described as 'roughness'—in the proportion of smooth surface cut away to make the grooved patterns on them; the nature of the pattern—whether the grooves ran along or round the cylinders and so on—was apparently quite irrelevant and not available to *Octopus* as a means of distinguishing between them. Evidently there is no central projection of the tactile sensory field in octopuses and the relative position of the tactile sense organs is not taken into account in building up an image of what an object handled is like. This is quite unlike ourselves where the relative position of receptors is most important in building up a picture of things we touch.

All of which returns us to something already implied by the consequences of statocyst removal on visual discrimination; *Octopus* seems unable to use proprioceptive information about the position of parts of its own body in learning.

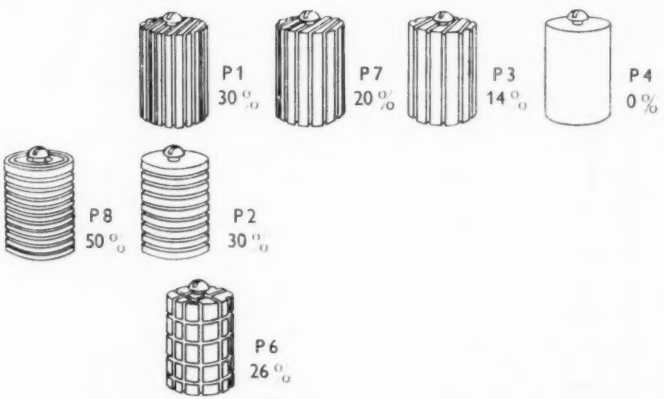


Fig. 4.—Objects used in experiments on the tactile sense of *Octopus*. The series is arranged so that there is a decreasing proportion of grooved to flat surface from left to right. This proportion is indicated as a percentage for each object. The objects in the top row differ only in the frequency of vertical grooves cut into them. P2 differs from P1 only in the orientation of the grooves cut into it. P6 has very nearly the same proportion of groove as P1, but the grooves are arranged to form a pattern of squares. Octopuses find P1, P2 and P6 difficult or impossible to distinguish, but can be taught to discriminate between the members of the top row (and between P8 and P4) relatively easily (from Wells & Wells (1957), *J. exp. Biol.* **34**).

We can confirm this peculiar feature of the organisation of *Octopus* by yet another sort of discrimination experiment. We can try to train octopuses to distinguish between objects of different weight. They cannot do it (Fig. 5). The result of these experiments is the more peculiar because *Octopus* quite obviously compensates for the weight of objects when it handles them. A heavy object is grasped in the normal way by an arm, which is passively extended by the weight of the object (blind animals generally sit on the sides

of their aquaria); the octopus 'takes up the slack' as it were, contracting its arm muscles, and then handles the object, passing it to the mouth or rejecting it in the normal way. A human observer can tell which object the animal is handling simply with information from internal ones. It cannot, moreover, learn to recognise external events signalled by internal receptors. This is not to say that internal information remains unused. The animal must, of course, make fine adjustments to

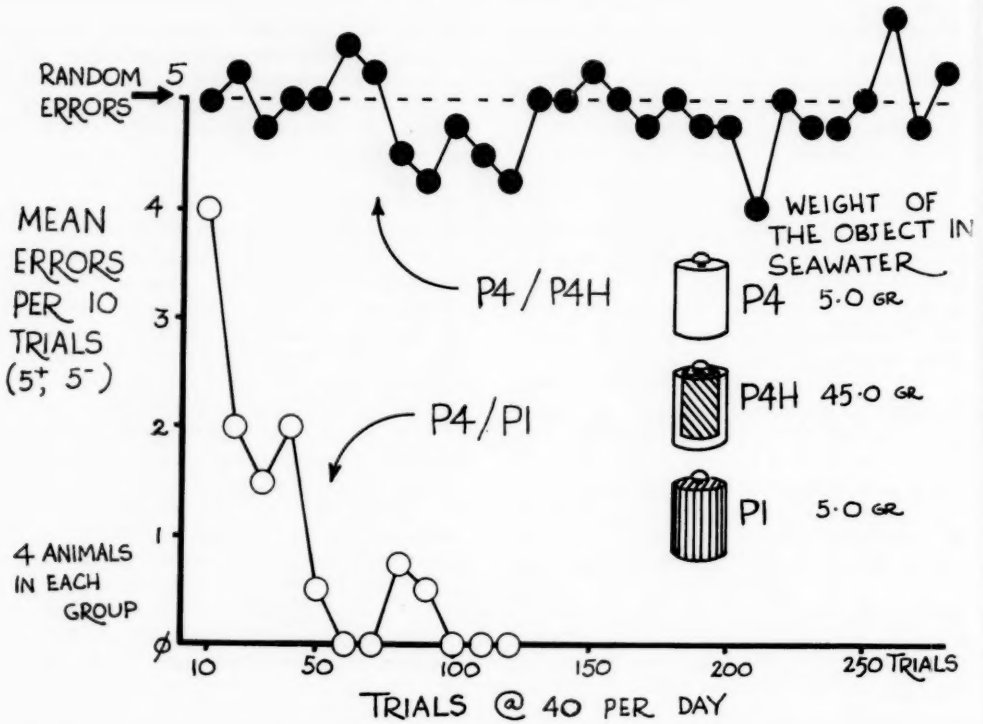


Fig. 5.—Tactile discrimination by octopuses. Four animals were trained to distinguish between the smooth perspex cylinder P4 and the grooved cylinder P1, learning this discrimination rapidly (the experimental results are plotted ○–○). Four other animals, trained in exactly the same way, failed to learn to distinguish between P4 and P4H, which was smooth like P4, but nine times as heavy (results plotted ●–●) (Wells, unpublished results).

by watching the octopus, but the animal itself is not capable of learning to recognise that holding one object requires more muscle contraction than holding the other.

It seems, then, that although *Octopus* is capable of integrating information from the various sense organs detecting outside events, it cannot learn to combine information from these external receptors the position of parts of its own body as a result of information from internal receptors, or it would be unable to move about as it does. But the whole business of postural adjustment seems to be dealt with at an automatic, reflex level. We have already seen how the eyes are kept horizontal by a reflex mechanism operating on information arising from the statocysts, and it appears that similar more or

less inflexible mechanisms look after details of all the motor responses that the animal makes; for instance, well integrated taking and rejecting movements—those that blind animals use when responding to objects that they touch—can be carried out even by isolated arms, chopped off from the body of the octopus. Distribution of organisation of responses to proprioceptive inputs has obvious administrative advantages, and it is possibly the only economical way of organising such a highly complex and flexible animal. *Octopus* has no skeleton, so that movements of parts are not restricted as in vertebrates, and this very flexibility would pose a horrific problem of integration for any wholly central mechanism. Even in ourselves where movements are restricted by the skeleton there is a tendency to simplify the brain's problem by delegating a good deal of postural adjustment to a spinal level, and in *Octopus* this tendency has apparently proceeded to the extreme where *all* the proprioceptive information needed for fine adjustments is dealt with in lower nervous centres—centres that do not themselves take part in the determination of which of a repertoire of responses by the animal as a whole shall be made in reply to any particular set of stimuli from the outside world.

Quite how this extreme state of affairs has come about is uncertain. It is possibly a consequence of descent from pelagic ancestors—octopuses are exceptional among cephalopod molluscs in that they live on the bottom, making extensive use of tactile stimuli; the rest, with few exceptions (*Sepia*, the cuttlefish and its close relatives) live in the open waters of the deep sea. Whatever the origin, the administrative economy of a largely reflex adjustment of posture has disadvantages for the present-day bottom-living *Octopus*. It means, as we have seen, that the animal cannot derive additional information about the things that it touches from the relative positions of the receptors stimulated by the contact. And it means that, despite Pliny's attractive story about the stone and the oyster, there is no possibility of the animal learning to make skilled movements.

From our point of view these limitations are a virtue. *Octopus* has a nervous system that does many of the things that our own does—the animal learns readily, to mention just one aspect of nervous organisation that we should like to know about—but it is a great deal less complicated. The octopus collects much the same sort of information about the world as we can ourselves, but it apparently makes different and far more limited use of this information. And because, in particular, it seems unable to use positional information, the brain of an octopus may prove to be a very great deal easier to analyse than the brain of any vertebrate.

But whatever we eventually hope to find out, the first stage in this analysis must be to discover what the octopus makes of the world around it.

References

BOYCOTT, B. B. (1954): 'Learning in *Octopus vulgaris* and other Cephalopods', *Pubbl. Staz. zool. Napoli*, **25,** 67–93. (How to catch and keep octopuses and details of experimental techniques.)

SUTHERLAND, N. S. (1960): 'Theories of shape discrimination in *Octopus*', *Nature, Lond.* (in press). (Mechanism of visual discrimination in octopus.)

WELLS, M. J. (1958): 'Nerve structure and function', *Advanc. Sci., Lond.* **57,** 449–57. (The relation of the work on octopuses to other lines of research on brain mechanisms—a review of the Section D proceedings at Dublin, 1957.)

YOUNG, J. Z. (1960): 'Learning and form discrimination by *Octopus*', *Biol. Rev.* (in press). (A review of the results of training experiments.)

WHAT FERTILISERS COULD DO TO INCREASE WORLD FOOD PRODUCTION

By Dr. H. L. RICHARDSON *Imperial Chemical Industries Ltd.*

I need not go into the reasons which made me take up the study of this subject, because they will be self-evident. Today every thinking person knows that the rapid increase in the world's population raises serious problems of food supply, especially in the less-developed countries, and that these problems are likely to become worse in the future.

For my part I am placing the emphasis on fertilisers, but I fully realise that they are only one factor in agricultural development. When farming is being improved, many other matters besides fertilisers require and get attention. It is obvious that good crops cannot be grown without adequate supplies of moisture; that selected and tested new varieties will give better yields than the old ones; that improvements in cultural methods and farming systems, including mixed farming and more production of local manures, will make still higher yields possible; and that crops have to be protected from weeds, pests and diseases.

It is further true that these improved techniques can do relatively little to raise average yields, on most soils, without chemical fertilisers; whilst fertilisers can do much more with the help of such improvements than they would be able to alone. There is what statisticians would call a positive interaction, and we cannot wholly isolate the effect of fertilisers from that of other factors.

In studying population and food problems we are looking ahead: we are concerned not only with what fertilisers can do to increase food production now, but with what they could do in the future. We may start by studying the results of the large-scale schemes of fertiliser field trials that have been carried out in many parts of the world, but this is only a beginning.

In the less-developed countries such trials are done, quite rightly, on the farms of peasant cultivators who are using primitive or traditional farming methods. With inexperienced farmers and unimproved crop varieties it is best to start by using fertilisers at low rates of application, and even so, other factors also limit fertiliser responses. Consequently a study of the results of these experimental programmes leads to rather modest estimates of what fertilisers can do to increase crop yields. We must then go on to examine what fertilisers could do, along with other major improvements, when the traditional agriculture of a country is being developed and modernised as it surely will be.

In this way I have studied the effects of fertilisers in a number of representative, agriculturally less-developed countries where large schemes of fertiliser trials and experiments have been carried out: namely, China, India, Ghana and Mexico. For an independent check on the conclusions reached, I have also examined the history of crop yields in England, Japan and Formosa; and yet another check is given by comparing the yields secured at agricultural research stations in underdeveloped countries with those of the peasant cultivators in the surrounding country.

Before going further into these other findings, I shall discuss the results of the fertiliser programmes in the countries first mentioned. The crops selected for study are as far as possible the chief cereal crops in each country, and they are thus the chief sources of the home food supplies. I have not forgotten that tubers, fruits and vegetables are also valuable sources of food, and that livestock, which require grassland and forage crops, provide important food needs, but there is not space to

include them as well. (*For a review of livestock and grassland aspects see Address by Dr. William Davies, Adv. of Science*, **xvii,** *No. 67, September, 1960.*) It is enough to say here that the other crops and grassland frequently show even larger responses to fertilisers than do the cereals, so that omitting them from consideration is not likely to result in the effects of fertilisers on food production being over-estimated.

FIELD EXPERIMENT RESULTS IN INDIVIDUAL COUNTRIES

Possibilities in China

(A) *Rice.* Before and during the last war, large programmes of fertiliser field experiments were carried out in China, and I have already summarised the results in other publications. The overall averages from nearly 300 rice experiments showed a total fertiliser response of 755 lb. of rough or paddy rice per acre, the average yield without fertilizers being 2100 lb. per acre. (This is a high yield figure for unfertilised rice, because the fertility of Chinese soils has been built up through the centuries by the traditional use of local organic manures.) The average direct response to fertilisers, used at rates close to ½ cwt. each of nitrogen, phosphate (P_2O_5) and potash (K_2O) per acre, was thus 36 per cent.

Although Chinese farming is efficient at a traditional level, and the soils are moderately fertile, there is still room for improvement in crop varieties, cultural methods, and pest and disease control. From experience in China, Japan and Formosa, I would put the average effects of such improvements, including their interactions with fertilisers, at around 15 per cent for better crop varieties, 15 per cent for cultural methods including water control, and 10 per cent for pest and disease control, giving a total increase of 40 per cent. In some localities much larger benefits might be expected, but elsewhere the rice-growing methods are already so good that there is little room for further improvement, except with much heavier manuring, and 40 per cent seems a fair general figure.

Adding this to the 36 per cent for direct response to fertilisers, already mentioned, we get a 76 per cent, or three-fourths, increase in yield as the overall result from using fertilisers, at ½ cwt. of each plant food per acre where needed, along with other technical improvements. The average rice yield in mainland China, in the last years for which dependable statistics are available, was 2330 lb. of paddy rice per acre, so that the improved yield on this basis would be 4100 lb. per acre.

By modern standards the rates of fertiliser application used in the Chinese field experiments were only moderate ones; in Japan and Formosa, where rice-growing conditions are nearest to those in China, the rice farmers are already using chemical fertilisers much more heavily, along with all the local manures and composts that can be secured. Nitrogenous fertilisers in particular are applied at an average of around 80 lb. N/acre in those countries, and the rates are still going up. From the results of experiments done in China at different rates of application, I calculate that if nitrogenous fertilisers were used there on rice at 80 lb. N/acre, along with phosphate and potash where needed at ½ cwt./acre, the direct effect of the fertilisers would be to increase yields by 46 per cent instead of the 36 per cent mentioned earlier. Adding 40 per cent for the effects of other technical developments, the combined effect of heavier fertiliser use and other improvements going on simultaneously would be to increase present rice yields by 86 per cent. This represents another 2000 lb./acre and would give an eventual average Chinese yield of 4300 lb. of paddy rice per acre.

As we shall see later, this figure is close to the average yield of rice in Japan today, which helps to confirm that the assumptions I have had to make are not too wide of the mark. Even this is not the end of the story, because with new varieties and improved water and disease control, still heavier manuring will be practicable: but we have taken it far enough to show, from information already in hand, what could reasonably be expected in the not-too-distant future.

(B) *Dry-land Cereals.* These include wheat, grown in the centre and north as a winter crop, and the summer grains—maize, millet and sorghum —which are important sources of food in western and northern China. There is not space to discuss them here in detail, but some conclusions follow based on calculations similar to those used for paddy rice.

Wheat yields and fertiliser responses are limited by the dryness as well as the coldness of the

Chinese winter. In consequence, the average yield of unfertilised wheat in the experiments was low, being only 1120 lb./acre, and so was the direct response to fertilisers, which totalled 460 lb./acre or 41 per cent. If, as with rice, we add another 40 per cent for the effects of the other improvements, the combined response to fertilisers and other developments likely to go on simultaneously would be 81 per cent, or an increase of four-fifths over current yields. The national average yield of wheat in China being 780 lb./acre, fertilisers (at ½ cwt. of each plant food per acre) and other improvements would add a further 630 lb./acre, giving a total improved yield of 1400 lb./acre. This is still low by the standards of intensive agriculture, but it is doubtful whether much more could be expected without irrigation. With irrigation—or a great extension of the area of wheat that is at present irrigated—dramatic further increases in Chinese wheat yields would become possible. This may be seen by comparison with what has been achieved in Mexico.

Summer Grains. Being grown during the warm and wet summer monsoon, these—maize, millet and sorghum—give higher unfertilised yields and larger responses to fertilisers than wheat does in China. In the Chinese field experiments the average response of the summer grains, excluding rice, to fertilisers was 755 lb./acre, the average unfertilised yield being 1800 lb./acre: an average direct response to fertilisers of 42 per cent. This is similar to the corresponding figures for rice and wheat in China; by a parallel line of argument, we should expect the combined response to fertilisers and other developments to be about 82 per cent, where the fertilisers are used where needed at ½ cwt./acre each of nitrogen, phosphate and potash per acre. From yield-response curves, the combined response, if the rate of application of nitrogen were raised to 80 lb./acre, would be very close to 100 per cent.

Possibilities in India

(A) *Rice.* The results from a wide range of fertiliser trials and experiments, including many thousands of simple trials on cultivators' fields, have been reported in recent years. Bringing together the information from various publications, I found an average response of rice to fertilisers in India of 590 lb. of rough or paddy rice per acre: this is the combined effect of nitrogenous and phosphatic fertilisers, applied where needed, at 30 lb. each of nitrogen and phosphate per acre. Figures for the average unfertilised yield in the trials are not available, but the overall average yield of paddy rice in India—most of which is unfertilised—is 1140 lb./acre. On this basis the direct response to fertilisers is 52 per cent.

Because Indian farming is more primitive than that in China, and Indian soils are less fertile—local manures being little used—a larger allowance can be made for the effects of other methods of agricultural improvements and their interactions with fertilisers. Cautious but reasonable estimates would be 20 per cent increase due to improved crop varieties, another 20 per cent for cultural methods, and 10 per cent for pest and disease control, the total being 50 per cent, instead of 40 per cent as in China. Adding this to the direct response to fertilisers, the combined effect of fertilisers and other developments proceeding simultaneously would be about 102 per cent: in other words, present rice yields would be doubled. The average improved yield of rice in India would then become 2300 lb. of rough or paddy rice per acre, which appears to be a realistic figure. It lies, for example, between the present average rice yields in Malaya (2000 lb./acre) and in Formosa (2700 lb./acre).

By modern standards the rates of application used in the Indian fertiliser trials were low ones: this was because (*a*) Indian farmers are unaccustomed to handling chemicals, and (*b*) the varieties of rice now grown in India cannot make use of much nitrogen. As the farmers gain experience and better rice varieties are produced, heavier rates of fertiliser use will become practical. From fertiliser response curves I estimate that 80 lb. of nitrogen per acre, used on improved varieties along with phosphate and potash at ½ cwt. per acre where needed, would produce an average direct response of 1040 lb. of paddy rice per acre in India, or 91 per cent of the present average yield. Adding to this another 50 per cent for other agricultural improvements would give an overall increase in yields of 140 per cent, with an average production of 2700 lb. of paddy rice per acre.

This is still a modest figure, comparable with the present average yield of rice in Formosa, but far below that in Japan, and with the further improvement and intensification of farming that is likely to occur in India under the stress of hunger, the

process of increasing yields is not likely to stop there. We may well expect that average yields of 3000 lb. of paddy rice per acre or over will eventually be achieved in India, if not in this generation then in the next. There is certainly no climatic barrier as such to obtaining high rice yields in India. In officially observed competitions, Indian rice farmers have already produced yields on individual fields of from 8400 to 11,200 lb. of paddy rice per acre.

(B) *Dry-land Cereals*: *Wheat*. As in China, wheat is grown in India during the dry, cold winter, and this leads to low yields and limited responses to nitrogen. With irrigation rather better results are obtained: from the results of the field trials I estimate that the average direct response to fertilisers (at 30 lb. each of N and P_2O_5 per acre) by irrigated wheat in India was 430 lb./acre, which would be about 45 per cent of the unfertilised yield. If, as with rice, we estimate a further 50 per cent for other improvements, the combined response to fertilisers, at the low rates used in the trials, and to other developments proceeding simultaneously, would be about 95 per cent.

Only one-fourth of the wheat in India is now irrigated, but irrigation is one of the major developments in the successive Indian Five-year Plans, and the proportion of wheat so treated will surely increase. Allowing for this and other improvements including greater fertiliser use, we may conclude that the average yield of all wheat in India could readily be doubled, and that further increases would follow. As the present average wheat yield in India is only 660 lb./acre, twice this figure at around 1300 lb./acre would still be a very modest yield by the standards of intensive agriculture. Having in mind what has already been done in Mexico, we might reasonably look forward to an eventual average yield of at least 2000 lb. of wheat per acre in India.

Summer Grains. These include, as in China, maize, millets and sorghum. Not much experimental work on these crops has been published in India, but I have seen the extremely poor, stunted and starved appearance of the crops themselves. There is no reason to doubt that what was found in China would hold good in India and that the present average yields of these crops could at least be doubled by the combined effects of fertilisers and other improvements.

Possibilities in Ghana

(A) *Guinea Corn and Millet*. These (Guinea corn is a sorghum) are the chief food crops in the Savannah belt of central and northern Ghana, as they are throughout this belt in West Africa. Large numbers of fertiliser experiments and simple trials have been carried out on both crops, and the average response of the two crops to low rates of fertiliser use (25 lb. N. and 22 lb. P_2O_5 per acre) was 486 lb./acre. The average unfertilised yield was 714 lb./acre, giving an increase of 68 per cent. Assuming, as for India, that the effects of other improvements would contribute another 50 per cent, then the combined response to small applications of fertilisers and the other improvements would be about 120 per cent. The average yield level would be raised to 1560 lb./acre.

Further, as Ghana farmers gain experience and learn how to use heavier dressings of fertilisers, yields will become even greater: doubling the experimental rates, which would provide dressings that are still moderate by modern standards, would give a direct fertiliser response of about 100 per cent and along with other improvements a combined increase of 150 per cent over current yields. The average yield level would then approach 1800 lb./acre. Similar yield figures have already been obtained in actual manurial experiments elsewhere in West Africa.

The poverty of the ordinary cultivator's crops of Guinea corn and millet in West Africa has to be seen to be believed. When travelling through the country I have often observed, among these sparse crops, occasional fertile spots where the yield would be several times as great. They may have been old hut sites. Again, it is very noticeable how the crops become taller, greener and heavier near the farmhouse compounds, where the plants receive household and human waste products. These observations in themselves indicate what manuring could do to raise the production of West African food crops

(B) *Maize and Other Food Crops*. These, including the tuber crops yams and cassava, are most important in the south of the country, in the woodland and forest belts. Here, fertiliser trials at rates similar to those mentioned under (A) have again given useful results, although there is no time to go into details.

The maize trials suffered from attacks of rust,

and the low responses to fertilisers, namely 20–30 per cent, cannot be considered typical; cassava responded very well, with an average direct response of 77 per cent; yams, which as far as possible are planted on the more fertile soils, gave a 23 per cent response, so that the average response for both yams and cassava was 50 per cent. With heavier rates of application than the small ones employed in the trials there would, of course, have been much larger responses; and, as with the crops already discussed, an allowance should also be made for the influence of other improvements proceeding at the same time, although we hardly have enough information to put actual figures on these additional effects.

Possibilities in Mexico

(A) *Wheat*. Since the last war a well planned and intensive programme of agricultural development has been carried out in Mexico, through co-operation between the Rockefeller Foundation and the Mexican Ministry of Agriculture. Remarkable results have already been obtained, particularly with wheat. This is mainly grown as an irrigated winter crop in Mexico; most of the soils have been exhausted by continuous cropping and are low in available nitrogen, so that even with irrigation the average yield is low. Under these conditions there have been very large and widespread fertiliser responses, and heavy rates of application have proved profitable.

In an experiment in which various rates of nitrogen were combined with different levels of soil moisture, the best irrigation raised the yield only from 587 lb. of wheat per acre to 612 lb./acre where no fertiliser was used. Nitrogenous fertiliser at increasing rates produced continuously higher yields, reaching 2154 lb. of wheat per acre with the poorest irrigation and 3990 lb./acre with the best, when the fertiliser was used at a rate of 135 lb. of N per acre. The increase with heavy nitrogen and better irrigation was thus 3403 lb. above the unimproved yield, a response of 580 per cent. The original yield was multiplied nearly seven times!

The figures well illustrate the type of interaction mentioned earlier, in which fertilisers become still more effective when other growth factors are also improved. Such heavy rates of nitrogen as these could only be used successfully because much research work had also been done to produce new wheat varieties resistant to lodging and disease.

Hundreds of field trials were carried out in the course of the research and development work in Mexico, but I do not have the results for comparison with those quoted for other countries. However, on most soils the fertiliser responses were comparable with those in the experiment just mentioned, even if rather less dramatic. Once the Mexican wheat farmers had been persuaded to try the new methods they adopted them enthusiastically, and it has been reported that some farmers are now harvesting 2700 to 3700 lb. of wheat per acre on the same land that yielded only 370 to 670 lb. per acre only four years earlier. In the course of achieving this, peasant farmers who had hardly seen chemical fertilisers before were soon applying dressings of up to 120 lb. of nitrogen per acre—heavier applications, for wheat, than those used even by sophisticated modern farmers in the U.S.A.

It required about ten years of experimental and development work and the gradual building up of a comprehensive farm advisory service before the peasants began to try the new methods; then they took to them rapidly. The effects of this can be seen in the average yields of wheat in Mexico, which were 732 lb./acre in 1946; 767 lb./acre in 1952; and 1401 lb./acre in 1958. In fact, by now the average yield of wheat in Mexico has almost been doubled, as a result of using fertilisers along with other improvements, and the experimental results suggest that the average yields could eventually be doubled again. At the least we can look forward with certainty to average wheat yields in Mexico three times those obtained before fertilisers and other improvements were introduced.

(B) *Maize*. Maize is the chief food grain in Mexico, and like wheat it has shown striking responses in fertiliser experiments, whilst many hundreds of demonstration trials have been done. So far the results in practice have been less striking than with wheat: this is partly because low rainfall or high altitudes limit maize yields and fertiliser effects in some regions of Mexico; partly because the maize growers in the more remote areas are more backward and slower to try new methods than are the wheat farmers. However, the yields of maize in Mexico are now beginning to increase: in 1946–7 the average maize yield was 660 lb./acre,

in 1957–8 it was 730 lb./acre, and the estimate for 1959 is 760 lb./acre. There is a large gap between this and the present U.S.A. maize yield of 2900 lb./acre, and if Mexican maize growers could only half bridge the gap, the average yield would be around 1800 lb./acre. In view of what has already been achieved with wheat, this would seem to be a modest target.

WHAT FERTILISERS HAVE DONE TO INCREASE CROP YIELDS

I could go on almost indefinitely giving examples based on field experiment results to show what fertilisers could do in other parts of the world, but the examples already given are widely representative of the less-developed countries, and they indicate that although the results vary with different regions and crops, yet large and progressive yield increases can be achieved. In order to have an independent check on the assumptions I have made and the conclusions I have reached, I shall now examine what fertilisers, along with other scientific improvements, have actually done to raise yields in several countries that have modern, intensive types of agriculture.

Wheat in England

The average yields of wheat per acre in England or the United Kingdom since early mediaeval times are shown below. (Here and elsewhere, yields originally expressed as bushels per acre are transposed into pounds per acre for ease of comparison, because a bushel of wheat, for example, weighs much more than a bushel of paddy rice.)

Period (A.D.)	*lb./acre*
c. 1250	380
c. 1350	500
c. 1550	940
c. 1750	1260
c. 1850	1640
1900	1890
1950	2350
1959	3200

The low yields of the thirteenth and fourteenth centuries were those of the mediaeval open-field system, and are comparable with the yields obtained by the most primitive methods of shifting cultivation in underdeveloped countries today. By the sixteenth century there had already been some improvement in cultural methods, and perhaps more use was made of farm manure; the yields of wheat then being obtained in England were rather higher than the average wheat yields in India, Pakistan or mainland China in recent years. With the coming of the enclosures, better crop rotations and other improvements, yields continued to rise in England during the eighteenth and nineteenth centuries: the figure for 1850, of over 1600 lb./acre, represented what could be obtained by good traditional farming methods including the use of farmyard manure, but practically no chemical fertilisers.

Since the mid-nineteenth century, with the gradual introduction of modern scientific methods including fertilisers, British wheat yields have continued to rise: in 1950 the yield was nearly 50 per cent above 1850, and in 1959 it was 95 per cent above 1850; in other words, the yields obtained by good traditional farming methods have almost been doubled. There can be no doubt that a large part of this increase, especially in recent years, has come from the increasingly heavy use of chemical fertilisers along with new varieties that resist lodging and disease. It would seem reasonable to attribute at least 50 per cent of the increase over 1850 yields to the direct effect of fertilisers: responses of this order are still commonly observed in fertiliser experiments with cereals in Britain. English farmers have some way yet to go before they reach optimum levels of fertiliser use on cereals, so that the traditional yields of 1850 will be considerably more than doubled before the process is finished. Even today, the yield of wheat in Britain is between three and four times what it was in Elizabethan England, and many times greater than in the early middle ages.

Rice in Japan

The average yields of paddy rice (rice in the husk) in Japan were as follows:

Period (A.D.)	*lb./acre*
8th century	1130
16th century	1690
1883–7	2190
1898–1902	2540
1918–22	3200
1938–42	3380
1948–52	3570
1959	4240

The story of rice yields in Japan is similar to that of wheat yields in England, except that throughout the period the yields of rice have been at a higher level in lb. of grain per acre. This is partly because, unlike wheat, rice grown in flooded fields usually has an assured water supply; and partly because rice fields have their own sources of soil fertility, in mud brought in by the irrigation water and in nitrogen-fixing micro-organisms. The early mediaeval rice yield in Japan was similar to the average yield in India today.

It is striking to see that, as with wheat in England, the mediaeval rice yield in Japan was just about doubled by the second half of the nineteenth century, as a result of improving the early cultural methods and using local manures. With the introduction of chemical fertilisers into Japan, along with scientific improvements in cultural methods and in varieties, the increase in average yields continued, and by the present time rice yields have very nearly doubled again. As with wheat in England, so with rice in Japan it would be reasonable to assume that at least half of this doubling of the yields formerly obtained by traditional methods can be attributed to the direct response to fertilisers. Yet higher yields can be expected as a result of research work now in progress in Japan, combined with still heavier applications of fertilisers.

Rice in Formosa (Taiwan)

In Formosa agricultural improvement began within living memory, so that we have almost under our eyes a picture of how a traditional type of Asian peasant agriculture can be developed by modern methods. The average yields of paddy rice were:

Year	*lb./acre*
1910–1	1555
1920–1	1632
1934–8	2195
1946	1677
1950–1	2168
1959	2650

The rice yield in Formosa early in the present century, with traditional farming methods that included local manures, was similar to that in Japan in the sixteenth century, and through technical improvements including fertiliser use it was raised by an average of about 40 per cent in the years before the war. By the end of the war, as the result of an almost complete lack of fertilisers, the rice yield fell back nearly to where it had started from—which shows how great a part the fertilisers had played in securing the pre-war 40 per cent increase—and since then, with increased usage of chemical fertilisers and other improvements, the yield has been raised well above the pre-war levels. By 1959 the average rice yield per acre in Taiwan had been increased by almost three-fourths above the unimproved yield at the beginning of the century, and the extent of the war-time fall when fertilisers were lacking suggests that over half of this increase, or something approaching 50 per cent of the original unimproved yield, could be attributed to the direct response to fertilisers.

The average yield of rice in Formosa is still well below that in Japan, although fertiliser use is at least as heavy. This is probably because two or even three rice crops a year are grown in most parts of Formosa. Consequently, short-period varieties that do not have time to produce extremely heavy yields are used. If we take the output of rice per acre per year, instead of per crop, then Formosa is already ahead of Japan: on double-cropped land, the annual output would average some 5300 lb. per acre as against 4300 lb. in Japan.

CONCLUSIONS

In spite of the variability of the results with different crops and countries, it is fair to say that on the whole the direct response to chemical fertilisers, used at low to moderate rates in less-developed countries, varies around 50 per cent of the unfertilised yield; and that the combined response to fertilisers and other methods of improvement going on simultaneously averages around 100 per cent. In other words, the present production of food crops in the less-developed countries could be doubled by using moderate fertiliser treatments and other techniques that could be put into effect without delay.

How much further the improvement in yields could go depends on such matters as the present fertility of a country's soils, and whether or not irrigation is available in dry climates. On the more fertile soils, such as those in China, where crop yields are already moderately high, doubling the original yields would be about the limit that could

reasonably be expected from the techniques now available. On the less fertile soils, such as those in India and Tropical Africa and America, the full application of modern intensive methods, including heavier fertiliser dressings and suitable new varieties, could not only double the original yields but double them again in many places, or at least add another 50 per cent. Thus in the long run the production of food crops from the present areas could even be multiplied three or four times. Extension of the crop areas, or of the irrigated areas, would still further enlarge the capabilities of using fertilisers: irrigation, in particular, along with other agricultural improvements, makes possible remarkable responses to heavy fertiliser dressings.

These broad conclusions are confirmed by what has actually been done in countries like England and Japan, where the low mediaeval yields of food crops were approximately doubled by improving the farming methods along the traditional lines, including local manures, and then doubled again by introducing the techniques of modern intensive agriculture. I estimate that about 50 per cent of this last increase could be attributed to the direct effects of chemical fertilisers.

Another pointer leading to the same general conclusion has been stressed by Dr. H. Greene of Rothamsted: namely that in underdeveloped countries the maximum yields obtained in fertiliser experiments at agricultural research stations are often three or four times the yields that the peasant cultivators around the station are getting.

Current Food Production Could be Multiplied Several-fold

The experimental results given earlier have all related to the principal food crops, and it is reasonable to assume that food production as a whole in most of the less-developed countries—the ones with the severest population problems—could be doubled and eventually trebled or quadrupled by using fertilisers and other modern agricultural methods.

The speed with which this can be done is very much a matter for the countries themselves. Although more field experimental work will be needed in individual countries to ensure that fertilisers are used with full efficiency, and numerous field trials will be wanted for demonstration purposes, we know enough to make a start. Additional experimental work, varietal improvement and so forth can be proceeding while the agricultural development is going on. The limitations to rapid increases in home food production are social, financial and educational rather than technical. In particular, the less-developed countries will have greatly to increase their farm advisory or extension services. One advisory officer in the field to every thousand farmers is not enough in the underdeveloped countries.

If the government of a less-developed country regarded the food problem as grave enough to justify such an expenditure of money and effort as would really get results, then food production could be doubled within a generation, which would take care of any conceivable rate of population increase. The process would not stop there, however: in the course of time food production could be doubled again; and by then, either better control of population increase or new scientific developments in food production would be influencing the picture.

I have said nothing about grasslands and the production of animal foods. This was not because I do not think them important—they are immensely so—but the subject is so complex that there is simply not room to do justice to it. Just as examples of what fertilisers can do, I would mention the improvement of pastures by superphosphate in Australia and New Zealand—which has increased output many-fold—and the grassland management investigations of I.C.I. Ltd., in Britain, which have shown how profits as well as production can be raised by the skilful use of fertiliser, particularly nitrogen, and good management.

In this paper I have focused attention on what can be done in the underdeveloped countries, because they are the ones where food and population problems are most serious. There is not space to discuss also the more highly developed countries with their intensive agriculture, but even in many of them fertilisers and associated improvements could further increase food production. Britain, for example, has increased her agricultural output by 60 per cent since before the war, and fertiliser use has been multiplied several times in doing so, yet the possibilities of further crop increase are not exhausted. In the U.S.A., with important crops like wheat and maize, although their average

yields have risen since pre-war the process of increasing them still has far to go. If there were no crop surpluses, the current U.S. yields of these crops could at least be doubled by using more intensive modern methods, including heavier fertiliser dressings. To increase food production further in countries that already have a highly intensive agriculture will be the most difficult problem, yet even here there are possibilities that are now being explored in agricultural research.

Why Not Top Yields?

I have shown the increases in food production that the world can expect from applying the knowledge we already have and the techniques generally used in modern intensive agriculture. There are still greater long-term possibilities that may be revealed by investigating how it is that the average crop yields obtainable by good intensive methods are so far below the 'top yields' given by certain favoured fields.

Crop competitions and officially observed measurements in many countries—even the less developed ones—have recorded yields from individual fields ranging from about 8000 to over 12,000 lb. of food grain per acre; say, around 5 tons an acre. By contrast, even the highest national average yields for food grains are between $1\frac{1}{2}$ and $2\frac{1}{2}$ tons an acre. We can guess at some of the reasons that make the favoured fields so fertile, but we do not fully know. If we really knew the explanation, then given the power of the scientific method and modern technology, it should eventually be possible to produce such yields to order on a large part of the cultivated land.

Intensive investigations into the why and wherefore of these high yields, or what prevents their general attainment, have already begun in countries such as Japan where the population and food problems are most pressing. If as much money and scientific effort was devoted to the problems of world food supplies as that spent, for instance, on atomic energy, rocket research and space travel, the answers would soon be found. Perhaps this stage will be reached by the turn of the century, if the 'population explosion' has not been brought under control. By then fertilisers may be reckoned as important as steel, for example, and required in similar quantities. When we know how to secure top yields more widely, we shall be able to look forward with confidence to producing very many times the present quantities of food in the world, and in this chemical fertilisers will continue to play a major part.

LOOKING AT science

I. The Association's Increasing Use of Visual Aids

The British Association is making increasing use of visual aids in presenting science to many different types of audience. As is reported elsewhere, in the last year the Association has provided lectures for over 100,000 people, and visual aids have been used in connection with many of these lectures.

But precisely because scientific visual aids are so numerous and come from so many sources, it is difficult for the scientist or teacher to keep abreast of the latest aids available to him. Yet many welcome such information, and it is significant that there has been a steady increase in the number of requests for invitations to the receptions which the Association has organised for science teachers. These were begun in 1959 with the generous co-operation of industrial firms. Each reception is devoted to a specific subject: physics, chemistry, biology, technical education, or general science. A programme of recent films is screened and guests have the opportunity of viewing a display of other related visual aids and a chance for informal discussion among themselves and with representatives from industry. In the current session five receptions have been arranged in London, and (for the first time) two further receptions in the provinces. Negotiations are proceeding with other industrial firms for further receptions both in London and the provinces.

Some of the films shown at these receptions are specifically designed for teaching, but others are of a kind which would only be suitable for extra-curricular activity. Well-produced and sometimes exciting presentations of science, they are frequently of interest to scientists and non-scientists alike. Particularly interesting, therefore, is a recent development initiated by the British Association Young People's Scientific Society in Aberdeen. It invited the British Association to select a science film programme which they arranged to screen to 10,000 children in the City. So successful was this venture that they are now arranging to present two further programmes by Easter 1961. The West Midlands Area Committee of the British Association has enthusiastically developed this idea. In October 1960, in co-operation with the Local Education Authority, it presented a B.A.-selected programme to 5,000 children in Coventry. These were children from Secondary Modern Schools who each attended one of the ten screenings during one week at the Coventry Technical College. At the time of writing arrangements are being made to present similar programmes to secondary modern children in Worcester City, Worcestershire, and Herefordshire. Discussions are proceeding with other Area Committees about the arrangement of similar events.

These developments mean that the British Association is now the largest single audience-producing body for scientific visual aids in Britain. But it is apparent that its work and the activities of other organisations in the field, could be greatly expanded if there were a more sympathetic appreciation of the value of presenting science visually. The Essex survey (reported in the September 1960 issue) provided a lot of information not only on the practical problems encountered by teachers in using visual aids but also on their varied attitudes to them. Many of their verbatim comments have been reported in a series of articles in the monthly journal *Film User*, commencing with the October 1960 issue. An immediate response to the first article was a

request by one local authority in the Midlands for the British Association to make a similar survey there. It is hoped that this will be possible in the near future. There is certainly great need for more factual evidence about the use and value of scientific visual aids. Such evidence would encourage a better use of existing material and might suggest new ways in which the sponsors, producers, and distributors could foster a more lively and effective use of visual material.

II. Science Film Congress in Prague

The XIVth Congress of the International Scientific Film Association was held in Prague from September 16 to 24, 1960, and was attended by 240 delegates and observers from twenty-five countries.

Two hundred and fifty films were screened during the eight working days, either in section meetings concerned with education, research and the popularisation of science; or in a festival of popular science films, open to the general public as well as to delegates.

Fourteen research films were awarded Diplomas of Merit, and nine popular science films were similarly honoured. In addition, two other popular science films, one from Bulgaria and another from Japan, received special mention. The education section did not make diploma awards.

There is a tendency at Congresses of this kind to focus undue attention on the spectacular film, which overshadows other entries because of its technical excellence or the originality of its theme. This tends to present in a wrong perspective an occasion which should provide the opportunity for professional film makers, and working scientists, to present many different aspects of science on film.

At Prague there was encouraging evidence that not only can professional film makers present science in an imaginative way, but that the working scientist is becoming more competent at expressing himself through the medium of film. This was particularly evident in the case of the research films. An outstanding example was Prof. Calabek's 'Autonomous Movement in Plants'—a beautiful time-lapse colour film study, notably alike for its quality as film, and for the interest of its subject matter.

Two Swiss Films, 'The Embryonic Development of the Tick' and 'The Embryonic Development of the Termite', were outstanding black and white studies made by scientists.

Original in its theme and competently executed was the American film, 'The Nature and Development of Affection'; an interesting study of the rearing of two rhesus monkeys with surrogate mothers.

The professional film maker has particularly excelled in the popular presentation of science, and the award winners in this category were notably for their wide range of subject matter.

Particularly interesting was the Chinese film, 'Mountain Canal'. This is a beautiful colour study of the construction of a canal, illustrating the ingenious and efficient use of a large labour force and primitive equipment to achieve technical results, which in the West would have been achieved with the minimum of manpower and the maximum of technical equipment.

Kurt Goldberger's film, 'Passport to Space', was a study of some aspects of research into space medicine. It provided a remarkable example of the ability of the professional film maker to simulate reality. With the exception of sequences shot in an aeroplane flying on a carefully selected elliptical course to induce a state of weightlessness, the entire film was made in the studio using professional actors and models. When one considers that this included models of a human centrifuge, and studies of the reactions of a subject in a pressure chamber, one can appreciate the technical mastery which such a film demanded.

One sees from these examples that excellent films can be made, either by a working scientist in the course of his researches, or by the professional film maker interpreting the scientist's ideas. But a third and equally effective method of film making is for the professional scientist to collaborate with a film maker who specialises in academic film making.

The European continent is well ahead of Great Britain in this respect, and at Prague one or more excellent examples of the work of University Film Departments was seen. Notably in the case of the Dutch film, 'Voice Reproduction—the Vibrating Larynx'. A study of larynx vibration had been made with the help of an ingenious studio rig. A larynx was suspended from wires and held taut in a frame. By pumping air into the larynx and using

additional tensioning wires, it was possible to simulate the movements which normally occur in human voice reproduction and, therefore, to film more accurately details which could not be observed so well using a human subject.

Another outstanding example was the Polish film, 'Sources of Energy of Blood Circulation', which postulated the theory that the heart does not act like a pump, but is rather a combination of two synchronously acting battering rams. This thesis illustrated by colour shots of the heart in action was sustained by an ingenious laboratory apparatus which reproduced this complex activity on the bench.

It will be realised that the great advances made since the war in scientific cinematography have depended to some extent on the development of more accurate and sensitive apparatus and the evolution of complex film techniques. Some of these were referred to in papers read at the Congress. Dr. N. Preobrazhensky, a Moscow Professor of Physics, showed how high-speed film studies had been made of the working of agricultural machinery. One such record at 2000 frames a second showed that a cotton harvester worked more efficiently when the plants were shaken at the moment of contact with the nozzles of the machine. In the case of a flax-puller it had been assumed that the crescent-shaped teeth in the pulling mechanism would facilitate their mutual cleansing but film studies revealed that no such cleansing took place.

Alexander Sakharov, a Russian film engineer, described the development of a special camera in the Soviet Union which operated on a new principle of intermittent motion, which relied on the fact that film entering and leaving the camera gate at constant speed, could be made to operate intermittently in the gate by retarding film movement with a pulsating tension pad. This induced elasticity in the gate, and the energy thus accumulated allowed the film to jump in regular motion.

A Czech film shown at the Congress, 'Improvement of Soaking Pits by Model Technique', provided an example of the use of the film camera to record detailed studies made with hydraulic models of air flow in a soaking pit operating at 1270°C. These studies revealed that air flow was different from that which had been assumed in theory, and a new layout of burners and ingots provided much more efficient operation.

The ciné camera continues to provide a wonderful tool for recording the unique event. This was seen in the Belgian study, 'Geophysical Expedition to the Nyiragongo Volcano in 1959'—a fascinating record of lava movement.

If a Conference like this teaches you anything, it is that scientists and film makers in all parts of the world are now able to present the results of scientific work, and to discover new scientific facts with the aid of a medium which can achieve wonderful results. Scientific film making is no longer the prerogative of a few technically advanced countries.

If at Prague one saw some excellent films from the West, such as Shell's 'The Living Soil', the Czech, 'The Crystallisation of Steel', the ingenious (if slightly arty) German Federal Republic film, 'Magic Tape', or the beautiful Hungarian nature study, 'Living Traps', one also saw some excellent films from countries as diverse as Bulgaria, Canada, the German Democratic Republic, Japan, Rumania, Uruguay and Bolivia.

ECHOES *from the Past*

The Agricultural Labourer

The progress of manufacture so far from lessening has rather increased the value of land. Great Britain retains and is likely always to retain its character as an agricultural country. Landowners occupy the highest positions and enjoy the greatest social privileges. Still, especially in the West of England, there are many persons remaining who resist all progress: the condition of the labourer is very little improved, and in some respects is worse than it used to be; wages are low, fuel and provisions dearer. Education has become a necessary of life for a family. The poor-rate is so administered as to quench every feeling of independence. In the West of England an agricultural labourer had, till lately, only 7*s*. or 8*s*. a week, and now only 8*s*. or 9*s*. Unless he is a horsekeeper or a shepherd, he has to pay out of this from 1*s*. to 1*s*. 6*d*., or more, a week, for house-rent, and to provide food, clothing, medical attendance, fuel, and every other necessary for himself, wife and family. Potato ground he pays a high rent for; and fuel he seldom gets except at a cost of as many hours of hard work in getting it as are its full value. He has three pints or two quarts of cider a day, and has a portion of his wages often paid in grist, which when corn is dear is an advantage, but otherwise a loss to him. He is often not allowed to keep a pig or poultry for fear of stealing food for them from his master. He works, nominally, ten or ten and a half hours a day, with an hour and a half deducted for meals. He is almost always, however, in reality kept a much longer time than this, and is seldom paid anything for overtime, except by bread and cheese in harvest time. Women get 7*d*. or 8*d*. a day for outdoor work, with a quart of cider, and boys smaller sums in proportion. The men breakfast before they leave home on teakettle broth, which consists of an infusion of bread and water with a little milk, when it can be got. For luncheon or dinner, which they take with them, they have coarse bread and a little hard, dry, skim-milk cheese at 3*d*. per lb. For supper, on their return home, they have potatoes or cabbage, with a very small slice of bacon sometimes to give a flavour. Butchers' meat they seldom get except it is given to them. They are unable to lay by anything; and few comparatively belong to benefit societies. They are long-lived, but even in their prime feeble, and at the age of fifty often crippled with rheumatism, the result of poor living, sour cider, a damp climate, hard work, and anxiety combined. There remains nothing for them then but parish pay and the Union.

British Association Meeting, Norwich, 1868.

'On the Purple Dye obtained from Coal-Tar'

'This dye, a specimen of which was exhibited, is a product of the oxidation of aniline by bichromate of potash. It is a bronze-coloured substance, dissolving in alcohol with a beautiful purple colour. It is with difficulty soluble in water, but more soluble in acidulated water. Like indigo, it is perfectly decolorised by the hydrated protoxide of iron, the colour being restored again by exposure to the air. It dissolves in concentrated sulphuric acid, forming a green solution, which, upon the addition of water, precipitates the colour unchanged. It is not affected by digestion with alcoholic solution of potash. It decomposes slowly at 250°C. It is applicable for dyeing and printing silk, cotton, or wool. Its colour is exceedingly intense, one pound of the solid substance dyeing no less than 200 lbs of cotton a moderately dark lilac. The colours thus produced are very permanent, standing the action of light and heat, acids and alkalies. Samples of silk dyed with it were exhibited.'

W. H. Perkin, British Association, Leeds, 1858.

* * *

On the Calorific Effects of Magneto-electricity, and the Mechanical Value of Heat

'Although it had been long known that fine platinum wire can be ignited by magneto-electricity, it still remained a matter of doubt whether heat was evolved by the *coils* in which the magneto-electricity was generated: and it seemed indeed not unreasonable to suppose that *cold* was produced there, in order to make up for the heat evolved by the other parts of the circuit. The author had endeavoured therefore to clear up this uncertainty by experiment. His apparatus consisted of a small compound electro-magnet, immersed in water, revolving between the poles of a powerful stationary magnet. The magneto-electricity developed in the coils of the revolving electro-magnet, was measured by an accurate galvanometer; and the temperature of the water was taken before and after each experiment by a very delicate thermometer. The influence of the temperature of the surrounding atmospheric air was guarded against by covering the revolving tube with flannel, etc. and by the adoption of a system of interpolation. By an extensive series of experiments with the above apparatus the author succeeded in proving that heat is evolved by the coils of the magneto-electrical machine, as well as by any other part of the circuit, in proportion to the resistance to conduction of the wire and the square of the current; the magneto, having, under comparable circumstances, the same calorific power as the voltaic electricity. Professor Jacobi, of St. Petersburgh, had shown that the motion of an electro-magnetic engine generates magneto-electricity in opposition to the voltaic current of the battery. The author had observed the same phaenomenon on arranging his apparatus as an electro-magnetic engine; but had found that no additional heat was evolved on account of the conflict of forces in the coil of the revolving electro-magnet, and that the heat evolved by the coil remained, as before, proportional to the square of the current. Again, by turning the machine contrary to the direction of the attractive forces, so as to *increase* the intensity of the voltaic current by the assistance of the magneto-electricity, he found that the evolution of heat was still proportional to the square of the current. The author discovered, therefore, that the heat evolved by the voltaic current is invariably proportional to the square of the current, however the intensity of the current may be varied by magnetic induction. But Dr. Faraday had shown that the chemical effects of the current are simply as its quantity. Therefore he concluded that in the electro-magnetic engine, a part of the heat due to the chemical actions of the battery is lost by the circuit, and converted into mechanical power; and that when the electro-magnetic engine is turned *contrary* to the direction of the attractive forces, a *greater* quantity of heat is evolved by the circuit than is due to the chemical reactions of the battery, the overplus quantity being produced by the conversion of the mechanical force exerted in turning the machine. By a dynamometrical apparatus attached to his machine, the author has ascertained that, in all the above cases, a quantity of heat, capable of increasing the temperature of a pound of water by one degree of Fahrenheit's scale, is equal to a mechanical force capable of raising a weight of about 838 pounds to the height of one foot.'

J. P. Joule, British Association Meeting, Cork, 1843.

* * *

BOOKS

The Royal Society, its origins and founders. Sir Harold Hartley, F.R.S., Editor.

The celebrations which were held during a week of last July, to commemorate the foundation of the Royal Society of London in 1660, evidently aroused much public interest in this country and, indeed, in the world at large. In that respect these tercentenary festivities showed a rather striking contrast to the commemoration, in 1912, of the 250th anniversary of the granting to the Society, in 1662, of its first Royal Charter; for these earlier celebrations had received comparatively little public attention. It may be supposed, indeed, that it is during the forty-eight years' interval between these two occasions, and chiefly during the latter part of it, since the Second World War, that official as well as popular opinion has begun to be clearly cognisant of the real significance of natural science in the present era of human civilisation, and thus to become interested in the events which played so important a part in the opening of that era, 300 years ago. Evidence of this more lively interest in the recent celebration was to be found in the numerous supplements and special articles, several of them richly illustrated, which appeared in connection with it in daily, weekly and other journals.

The Royal Society itself has made, in the same connection, two special publications of its own—a new *Brief History of the Royal Society* by Professor Andrade, and the larger volume here under review, on *The Royal Society, its origins and founders*, which ranks as a special issue of the Society's well-known series of 'Notes and Records'. No fewer than twenty-one distinguished writers, all of known authority on the history of science and scientists, have contributed, each of them to one or more of the twenty-four chapters of this history of the Royal Society's origins. Sir Harold Hartley has not only been a joint author of several of the biographical chapters, each devoted to the personality, and to the greater or smaller scientific achievement, of one of those here recognised as the Society's founders; but he has also been responsible as chief editor for the book as a whole, and for a Preface, and for a retrospective Epilogue, which raises a number of points of additional and more general interest.

In the first and, very naturally, the longest and most important of the chapters, Professor Douglas McKie gives, as was to be expected, a scholarly and widely informative survey of the general conditions and the individual discoveries and enterprises in the period from 1500 to 1650, which heralded the escape by science, as earlier by the arts, from the domination of classical authority, and thus prepared the way for the corporate action of a group of British enthusiasts for this 'new' or 'experimental' philosophy, which effectively founded the Royal Society in 1660; although Professor McKie seems to attribute more importance than some others have done to the statement of John Wallis, himself one of the formal founders in 1660, that 'I take its first Ground and Foundation to have been in London about the year 1645 (if not sooner)'.

It is also made clear in Professor McKie's introductory review that, whereas such pioneer works of theory and observation as those of Copernicus and Vesalius, both published in 1543, had come from the continent of Europe, science had to wait for two English investigators to provide the first and still pre-eminent examples of scientific discovery by the use of experiment, in William Gilbert's *De Magnete* (1600) and William Harvey's *De Motu Cordis* (1628). Both these great scientists were practising physicians, attending the Sovereigns of their respective generations. Harvey's attachment to the service of Charles I would, apart from his age, have prevented him from

joining the group at the earlier London meetings; and he died three years before 1660. It may be noted, however, that, of the group meeting in London from 1645 onwards, no fewer than five, of the seven whom Wallis recalled by name, were physicians who must have known Harvey, and that Harvey's discoveries figured prominently among the subjects of their discussions and further experiments.

We come then to the choice made of individual subjects for the biographical memoirs, which constitute the main part of the book—twenty-two of its twenty-four chapters. Twelve of them choose themselves as 'founder-members', since they happened to be present at the particular meeting at Gresham College, after one of Wren's lectures, on November 28, 1660, at which the decision was taken for the effective foundation of what became the Royal Society; though some of them, according to the accounts given here by their respective biographers, would have had little or no claim for such commemoration on the ground of their personal contributions to scientific knowledge. Most of the twelve, on the other hand, could show important contributions to mathematical or experimental science, all gave evidence of a widely ranging enthusiasm for different aspects of the 'new philosophy', while for some, such as Robert Boyle and Christopher Wren, the claim to pre-eminence, among the scientific pioneers of all the world, would surely be irresistible. It is even thrilling to read again of Boyle and Wren, known to the world for such widely different lines of achievement, collaborating in experiments on blood-transfusion! Then, in addition to those present at the foundation meeting, we have chapters on eight others, chosen from the list of those nominated at that meeting as 'willing and fit to joyne them in their design', or from that of the additional Fellows elected during the Society's first official year, after its incorporation by Royal Charter. For some of these, again, the choice for recognition as 'founders' could not be called in question—such as King Charles the Second, 'Founder and Patron'; John Wallis, a member from the first of the preliminary meetings, and recorder of their activities; William Croone who, though not present at the foundation meeting, was chosen then to be the first Register (Secretary); Oldenburgh, the first to be elected as Secretary after the Charter, and founder of the Philosophical Transactions; and Robert Hooke, who showed so astonishing a range of scientific achievements of the highest order, that Professor Andrade claims recognition for him as 'the greatest inventive genius who ever lived'. There may be one or more of the rest who would not have been chosen by everybody for inclusion, out of the many possible candidates; some, perhaps, might have preferred one or more of the other earlier enthusiasts who, like Wallis, happened not to be present at the foundation meeting. In any case, however, the choice for such a book had to be limited; and it may well be doubted whether any editor could have made one more likely to be generally acceptable, than that actually produced by Sir Harold Hartley and his advisers.

And finally, it may be observed that, in more than one chapter, and especially in that dealing with John Wilkins and in Sir Harold Hartley's Epilogue, a proper and not too familiar emphasis is given to the great service done by these early scientists to the use of English prose, then being newly accepted as a proper vehicle for learned communications, by their insistence on a simple precision and an elegant economy of expression. Wilkins is quoted as saying: 'The greatest learning is to be seen in the greatest plainness', and 'When the notion is good, the best way to set it forth is the most obvious plain expression'. Sprat again, in his *History*, records of the early Fellows of the Royal Society that 'They have exacted from all their members a close, naked, natural way of speaking'. There are occasions, perhaps, today, when one might be inclined to wish that the exaction could be still in force, and always effective.

Altogether, Sir Harold Hartley, and the members of his variously qualified and distinguished team of authors, are to be heartily congratulated on the result of this undertaking, worthily commemorative of a great occasion. The book ought to make a strong appeal to all serious students, whether of science or of social history, in this country and far beyond it. It should be available in all important scientific libraries, and in many general and public ones.

H. H. D.

NEW BOOKS FOR THE GENERAL READER

The following notes are published by courtesy of the National Book League. They will be reprinted in the next annual supplement to SCIENCE FOR ALL, *an annotated reading list for the non-specialist, published for the N.B.L. by the Cambridge University Press.*

GENERAL

Coulson, C. A. SCIENCE, TECHNOLOGY AND THE CHRISTIAN. *Epworth Press*, 1960, 8*s*. 6*d*. 111 pp.

The Beckly Social Service Lecture 1960. A discussion of the problems raised for Christian thought by modern developments in science and technology, with a chapter on moral responsibility. (261)

METHOD AND COMMUNICATION

Viaud, Gaston. INTELLIGENCE: ITS EVOLUTION AND FORMS. Trans. by A. J. Pomerans. *Hutchinson* (*Arrow Science*), 1960, 10*s*. 6d.; paper, 5*s*. 127 pp. 18 text figs.

A brief study of 'intelligence seen in its evolutionary perspective' and the variations in intelligent behaviour in various animal species, children and adult man, with chapters on conceptual and rational thought. In conclusion the theory of alternating phases of technical invention and speculative thought is discussed. (151)

PHYSICS

Duquesne, Maurice. MATTER AND ANTIMATTER. Trans. by A. J. Pomerans. *Hutchinson* (*Arrow Science*), 1960, 10*s*. 6*d*.; paper, 5*s*. 127 pp. 38 text figs.

An account by the Director of Research in Nuclear Physics at the Radium Institute, Paris, of the discovery of antimatter, with a discussion of its implications and some interesting suggestions on its relation to the passage of time. Unlike other books in the series, this is beyond the reach of most 'general' readers; a good grounding in physics and mathematics is required. (539.721)

THE SCIENCE STUDY SERIES. *Heinemann*, each 4*s*. 6*d*.

This is a new paperback series originating from the Massachusetts Institute of Technology. Its 'primary purpose' is 'to provide a survey of physics within the grasp of the young student or layman'. The series is planned to run to over seventy titles and the individual books naturally vary in style and achievement. The first five volumes are:

Bitter, Francis. MAGNETS: THE EDUCATION OF A PHYSICIST. *Heinemann* (*Science Study*), 1960, paper, 4*s*. 6*d*. 155 pp.

The author, Professor of Physics at the Massachusetts Institute, describes his own development as a scientist, introducing magnetism, in which much of his research work has been done, as a 'personal voyage of exploration'. (538)

Boys, Sir Charles Vernon. SOAP BUBBLES AND THE FORCES WHICH MOULD THEM. *Heinemann* (*Science Study*), 1960, paper, 4*s*. 6*d*. 156 pp. 68 text figs.

A reprint of a classic of popular science originally published in 1902 (rev. edn. 1916), and based on lectures delivered to a juvenile audience. The four lectures are a delight to read and the experiments described are simple for home experimenters to follow. (532.6)

Griffin, Donald R. ECHOES OF BATS AND MEN. *Heinemann* (*Science Study*), 1960, paper, 4*s*. 6*d*. 156 pp. 15 text figs.

Donald Griffin in 1938 carried out the pioneer experiment by which the high-pitched navigational clicks made by bats were detected. In this book he reports on how studies of bats, porpoises, whirligig beetles, electronic radar and sonar are expanding man's knowledge of physics, and how this knowledge may help blind people. (534.2)

Hughes, D. J. THE NEUTRON STORY. *Heinemann* (*Science Study*), 1960, paper, 4*s*. 6*d*. 158 pp. 39 text figs.

Only trained physicists can hope to understand the character and potentialities of neutrons. This clearly expressed account intended for the non-specialist may help to give the general reader a glimmering of the importance of these 'fundamental particles'. (539.721)

Hurley, Patrick M. HOW OLD IS THE EARTH? *See under* Geology, below.

CHEMISTRY

Warring, R. H. INSTRUCTIONS IN CHEMISTRY. *Museum Press* (*Brompton Library*), 1960, 12*s*. 6*d*. 148 pp. 72 text figs.

To encourage the practical beginner: instructions for 106 very simple experiments which can be carried out at home, presented without the use of formulae. (540)

ASTRONOMY

Cousderc, Paul. THE WIDER UNIVERSE. Trans. by Martin Davidson. *Hutchinson* (*Arrow Science*), 1960, 10*s*. 6*d*.; paper, 5*s*. 128 pp. 4 plates, 29 text figs.

A study of the universe beyond the solar system. Not easy reading but accessible to the layman. (523)

GEOLOGY

Hurley, Patrick M. HOW OLD IS THE EARTH? *Heinemann* (*Science Study*), 1960, paper, 4*s*. 6*d*. 160 pp. 8 plates, 27 text figs.

This study deals with the structure of the earth and its origin, with particular attention to radioactivity and the measurement of geologic time. (551)

McKay, Herbert. HALF-HOURS WITH GEOLOGY. *O.U.P.* (*New Playbooks of Science*), 1960, 8*s*. 6*d*. vi, 140 pp. Diagrams by Alexander Murphy.

A crisply presented little book which, though intended for young readers ('11 and up') is a useful introduction for anyone without previous knowledge of the subject.

NATURAL HISTORY

Fisher, James, and others, ed. NATURE: EARTH, PLANTS, ANIMALS. Editorial board: James Fisher and Sir Julian Huxley with Sir Gerald Barry and Dr. J. Bronowski. *Macdonald Illustrated Library*, 1960, 45*s*. 363 pp. Illus. throughout (many in colour) by Hans Erni. $10\frac{3}{4}$ in. $\times 8\frac{1}{4}$ in.

An extremely attractive pictorial general knowledge book. A first section on geology leads on to an ambitious unfolding of the story of life on earth. To quote the introduction, 'it is a book of physiogeography (physical geography) and biology, and an introduction to the scientific study of earth, weather, bodily structure, function, heredity, behaviour, the interrelations of life and its environment, fossils, the geographical distribution of living things, man, and how these evolve in time.'

Illustrations on almost every page are integrated with brief authoritative text. A glossary and an appendix giving the classification for all the major groups of animals and plants are provided. (574)

(This is a companion volume to SCIENCE: CHEMISTRY, PHYSICS, ASTRONOMY, published earlier in the year.)

Font Quer, P. THE ANATOMY OF PLANTS. Trans. from Spanish by D. H. R. Newton. *Hutchinson* (*Arrow Science*), 1960, 10*s*. 6*d*.; paper, 5*s*. 128 pp. 49 text figs.

Simple expositions of the characteristic structural features of plants. Starting with the structure of plant-cells Dr. Font Quer proceeds to describe 'the structure and organs made of the different kinds of cells, and the mechanisms by which species of plants are propagated'. Elegantly illustrated. For the non-specialist genuinely interested in botany. A companion volume, PHYSIOLOGY OF PLANTS by the same author is also included in the series. (581.4)

Godfrey, G., and Crowcroft, P. THE LIFE OF THE MOLE. *Museum Press*, 1960, 15*s*. 152 pp. Frontis., 31 text illus.

A detailed monograph for zoologists, on a subject which will appeal also to many farmers and amateur naturalists. Mole movements have been traced by an ingenious method using radioactive labels and geiger counters. (599.33)

Mertens, Robert. THE WORLD OF AMPHIBIANS AND REPTILES. Trans. by H. W. Parker. *Harrap* (*Living Nature*), 1960, 63*s*. 207 pp. 140 photographs (31 in colour). $11\frac{1}{4}$ in. $\times 8\frac{3}{4}$ in.

Prof. Mertens describes reptiles and amphibians of the world, their structure, way of life and distribution, their place in the story of evolution and their relationships to the inanimate world, other animals, and man. The photographs, as usual in this series, are outstanding.

Postma, C. PLANT MARVELS IN MINIATURE: A PHOTOGRAPHIC STUDY. *Harrap*, 1960, 45*s*. 173 pp. 77 plates. 13 in. × 10 in.

Photographs of plant structures under progressive magnification, with brief explanations.

Yonge, C. M. OYSTERS. *Collins* (*New Naturalist*), 1960, 21*s*. xiv, 209 pp. 31 half-tone illus. 72 text figs.

A scientific monograph so presented as to appeal to the general reader as well as to the specialist. 'The structure, the mode of functioning, the habits, the unexpectedly complex life-history of oysters, their history in remotest time, the growing interest in them of man first as a necessity of life and then as one of its major luxuries, so as objects of scientific enquiry, of literary allusion and of artistic portrayal, and finally as domestic animals the basis in four continents of vast schemes of aquiculture—some reference in text, quotation or illustration must be made to all in any truly balanced account of oysters.' So writes Prof. Yonge in his introduction. (594 1)

PAPERBACK EDITIONS of books previously mentioned in the N.B.L. bibliography

SCIENCE FOR ALL:

Lyttleton, Raymond. THE MODERN UNIVERSE. *Hutchinson* (*Grey Arrows*), 1960, 3*s*. 6*d*.

Rothschild, M., and Clay, T. FLEAS, FLUKES AND CUCKOOS. *Hutchinson* (*Grey Arrows*), 1960, 6*s*.

Rolt, L. T. C. ISAMBARD KINGDOM BRUNEL. *Hutchinson* (*Grey Arrows*), 1961 (Jan.), 5*s*.

Bronowski, J. THE COMMON SENSE OF SCIENCE. *Penguin* (*Pelican*), 1960, 3*s*. 6*d*.

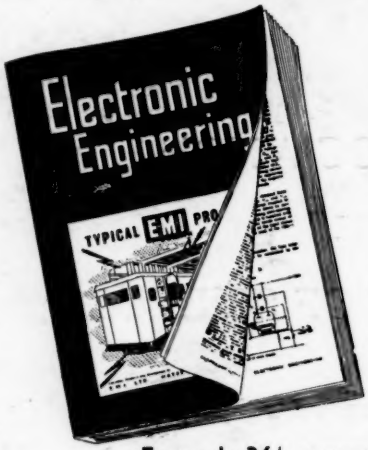
Printed in Great Britain by Spottiswoode, Ballantyne & Co. Ltd., London and Colchester

BRITISH ASSOCIATION

FOR THE

ADVANCEMENT OF SCIENCE

The British Association remains unique as an independent institution of national reputation, which brings almost the whole range of sciences within its scope and opens its membership to all who are interested in the progress of science. Founded in 1831 to convince an indifferent public and Government that science was important and worth backing, the Association—as its history bears witness—succeeded magnificently in its original purposes. Today science is of paramount importance to the Country and one of the Association's main tasks is to promote a better understanding of the significance for industry of scientific research and its impact, through its applications, on society as a whole.



The science of electronics has become the keystone of this modern age. It has penetrated into practically every field of research and has completely revolutionized the science of measurement. The education of the modern enquirer is therefore incomplete without a knowledge of electronics. A post graduate course in this subject is to be found in— *"ELECTRONIC ENGINEERING"* the industry's leading technical journal.

For only 36/- a year you can have *"ELECTRONIC ENGINEERING"* sent to you each month.

Electronic Engineering 28 Essex Street, Strand, London, W.C.2

Published by MORGAN BROTHERS (Publishers) LTD.
Proprietors of "THE ENGINEER"

BOOKS
ON
NATURAL HISTORY
AND
BIOLOGY

New, Second-hand, Old and Rare

CATALOGUES ON REQUEST

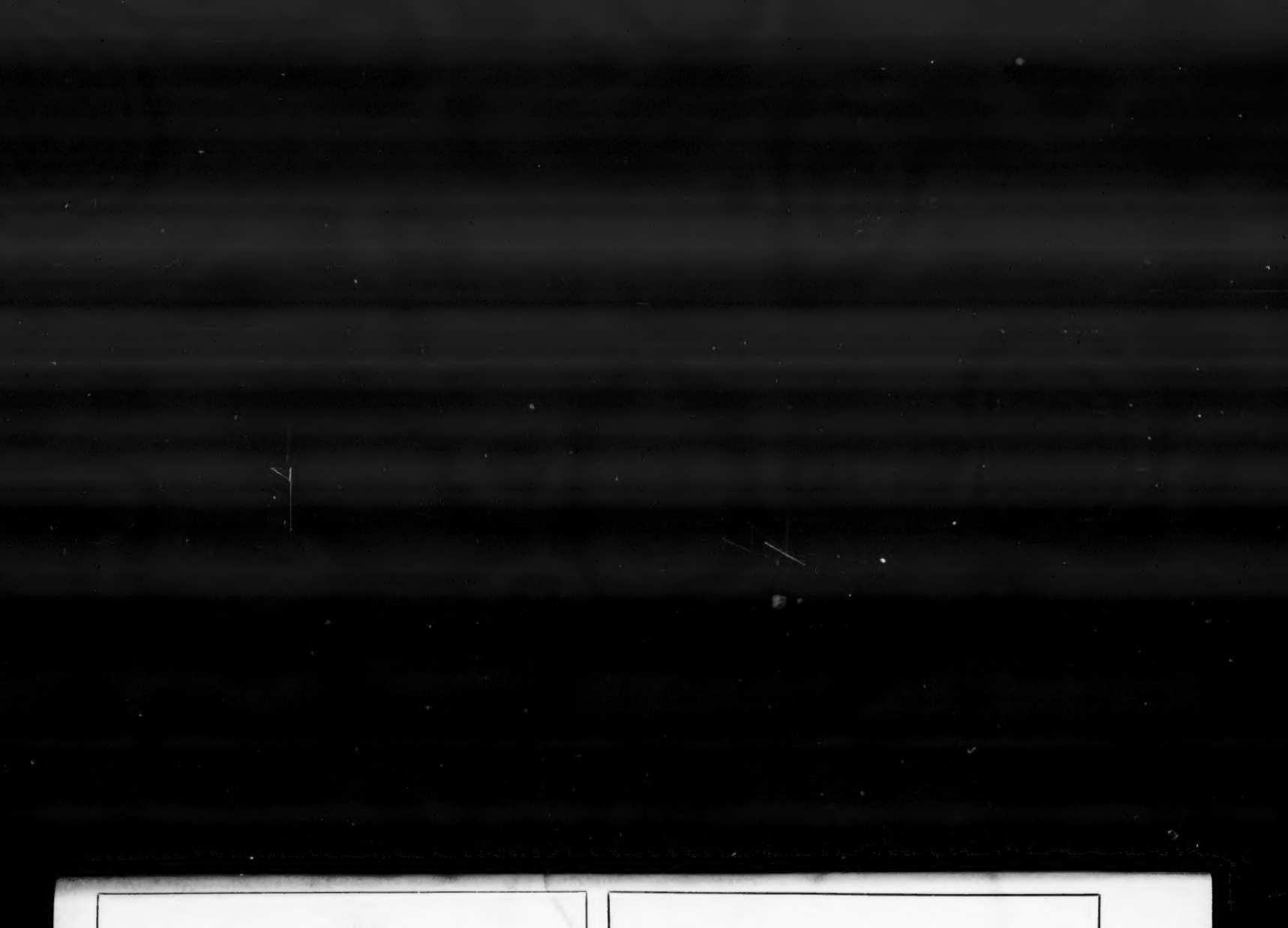
WHELDON & WESLEY LTD.

LYTTON LODGE, CODICOTE,
Near HITCHIN, HERTS.
Phone: CODICOTE 370

IMPORTANT

Readers are reminded that all Books reviewed or advertised in this issue may be obtained promptly from:

W. & G. FOYLE LTD

119-125 CHARING CROSS ROAD
LONDON WC2

Gerrard 5660 (20 *lines*) *Open* 9–6 (*inc. Sats.*)
2 mins. from Tottenham Court Road Station